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AUTOMATED STRENGTH DETERMINATION FOR INVOLUTE FUZE GEARS.(U)

FEB 82 G G LOWEN, C KAPLAN DAAK10-79-C-0251

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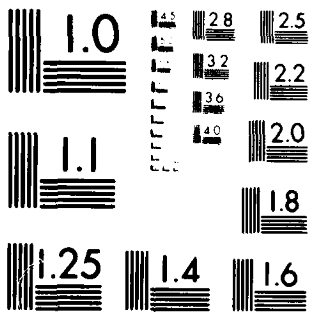

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This investigation developed two computer programs which allow the determination of the tooth profile coordinates, together with the associated Lewis gear strength and AGMA geometry factors, for all types of involute gears including fuze gears. These two programs differ only in the manner in which the root portion of the teeth is obtained. The origins of the involute and trochoid coordinate expressions and of all programming schemes are discussed in detail. Sample runs and operating instructions are provided.

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TABLES

FIGURE

1. INTRODUCTION

This report describes the development and use of certain computer programs which allow the determination of relevant information with respect to strength calculations for all types of involute gears including fuze gears.

Both programs, LEWIS CIRCLES and LEWIS ENVELOPE, furnish the coordinates of the left side of any involute tooth (See Figure 1), together with the associated Lewis and AGMA geometry factors. The determination of these factors is based on the assumption that the maximum contact force F is applied at the tip of the tooth and that therefore the origin V of the inscribed Lewis parabola is located at the point of intersection of the line of action of this force and the tooth centerline. The point of tangency between this parabola and the tooth profile, together with the x-coordinate XTAN required for the determination of the above factors, is found by an iterative process.

The involute portion of the tooth profile is obtained in both programs by a mathematical description of the unwinding of the base circle tangent. The trochoid or root portion of the tooth profile is obtained by two different methods.

Program LEWIS CIRCLES finds the associated coordinates by a simulation of the hob cutting or drafting process, while program

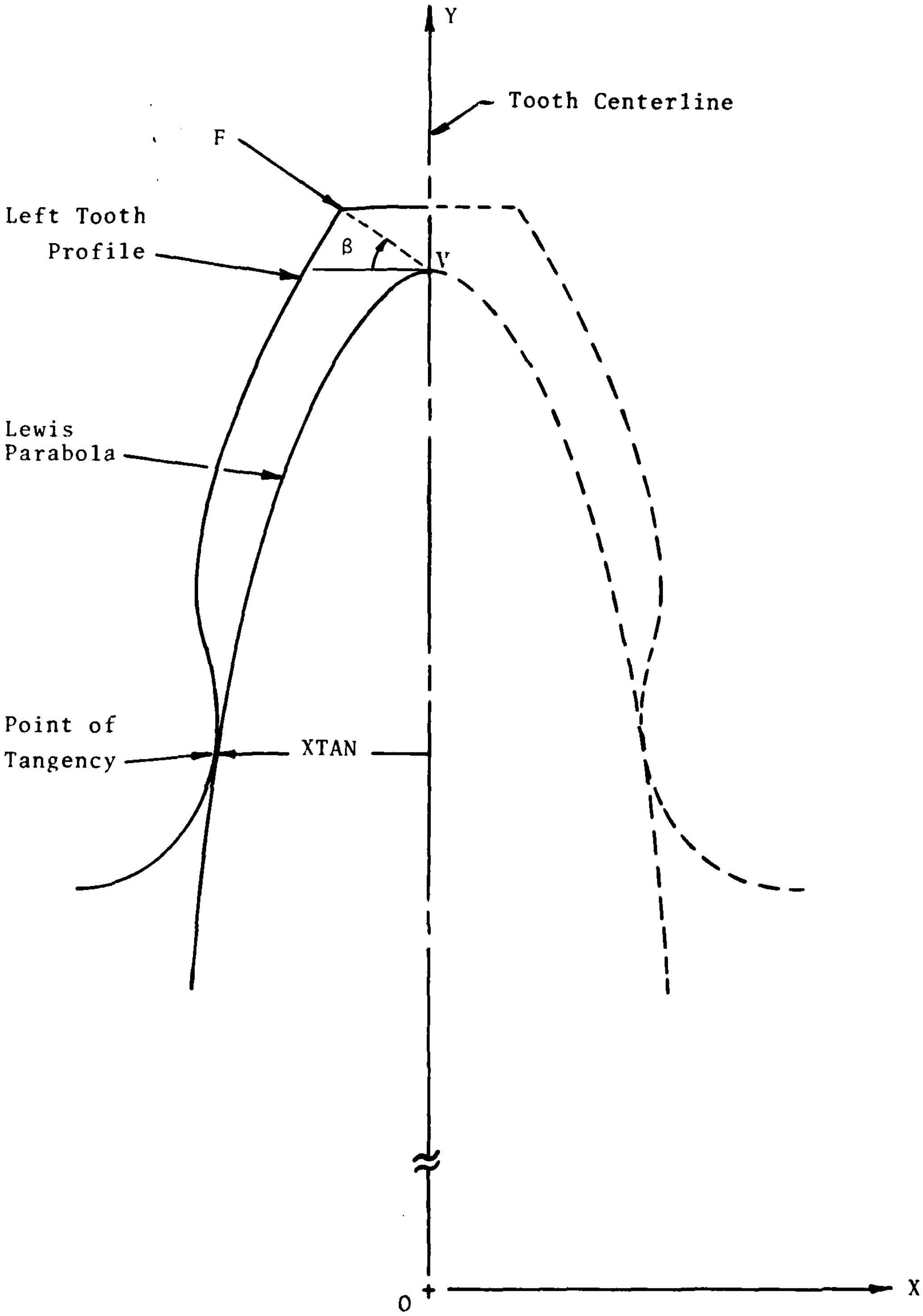


Figure 1. Tooth profile and Lewis parabola for maximum load F

LEWIS ENVELOPE makes use of an analytical method, based on the relationship between generating curves and envelopes. While the results of both programs are identical, program LEWIS CIRCLES cannot be used when the hob fillet radius is zero.

To assist the user as much as possible with the details of operation of these programs, the following outline of input and output parameters, is given: (<u>The input and output parameters of both programs are identical</u>).

a. <u>Input Data (All given for unity diametral pitch)</u>

1. Number of Teeth
2. Effective distance (see Appendix B)
3. Unity diametrical pitch
4. Hob pressure angle
5. Circular tooth thickness at standard pitch circle
6. Hob fillet radius
7. Gear tooth addendum
8. Angular increments for involute and trochoid generation

b. <u>Output Data</u>

1. Results of various intermediate computations

2. Lewis factor

3. AGMA geometry factor

4. Various parameters associated with the point of tangency between Lewis parabola and tooth profile

5. Coordinates of Tooth profile

As a further aid to the user, material on which this report is based is compiled in the appendixes.

Appendix A: Determination of Involute Coordinates

This appendix gives the derivation of the x and y-coordinates of the involute portion of the tooth profile of an arbitrary tooth in terms of the coordinate system shown in Figure 1. Use is made of the angle α which describes the unwinding of the base circle tangent.

Appendix B: Determination of Path Coordinates of Effective Rack Point

After defining the concepts of effective rack point and effective distance for hobs with and without fillet radii, this appendix gives derivations for the path coordinates of the effective rack point for undercut and non-undercut gear teeth. In order to accomplish this, the generating angle ψ, which describes the rolling of the rack pitch line on the gear pitch circle, is introduced. Again, the results are given in terms of the tooth centerline coordinates shown in Figure 1.

Appendix C: Generation of Tooth Root in Presence of Fillet Radius on Rack Cutter

Two methods of obtaining the coordinates of the tooth root are shown. The first method simulates the cutting or drafting process and is used in program LEWIS CIRCLES. The second method, which is based on certain relationships between generating curves and envelopes, forms the basis for the root generation in program LEWIS ENVELOPE.

Appendix D: Initial and Final Angles for Trochoid and Involute Generation

This appendix first gives a review of existing procedures for the determination of the inner form radius for undercut and non-undercut teeth. Subsequently, expressions for the limits of the generating angles α and ψ are derived for both types of teeth.

Appendix E: Gear Strength Calculations. Determination of Lewis and AGMA Geometry Factors

Initially, the origin of the Lewis gear strength formula is reviewed and expressions for the determination of various associated parameters are derived. Subsequently, the iterative procedure for finding the point of tangency between the Lewis parabola and the tooth profile, which is used both in program LEWIS CIRCLES and in program LEWIS ENVELOPE, is explained.

Appendix F: Program MATRIX

This appendix describes and lists program MATRIX, which is used to determine the size of the arrays in the two computer programs. It also contains sample outputs of program MATRIX which pertain to the sample runs of both LEWIS programs. (See Section 3.)

Appendix G: Program LEWIS CIRCLES

A complete listing of the program LEWIS CIRCLES is given, together with outputs of the two sample runs.

Appendix H: Program LEWIS ENVELOPE

This appendix contains a complete listing of program LEWIS ENVELOPE. In addition, the results of the two sample runs are shown.

2. DESCRIPTION OF COMPUTER PROGRAMS

The following section gives descriptions of the essential steps of the programs LEWIS CIRCLES and LEWIS ENVELOPE. Program LEWIS CIRCLES is listed, together with sample runs, in Appendix G. Appendix H furnishes the same for program LEWIS ENVELOPE. The specific sample runs of both programs are discussed in Section 3.

The input and output parameters of both programs are identical and will therefore only be discussed in detail in conjunction with program LEWIS CIRCLES.

Since the vector Y and the matrix X, as used for the determination of the root profile in LEWIS CIRCLES (see also Appendix C-2: Iterative Method of Obtaining Root Profile), may be very large, it is necessary to use care in the dimensioning of these arrays as well as in the request for computer storage space. Appendix F gives program MATRIX which allows the determination of the sizes of Y and X, as well as of the vectors X1 and Y1 which are used for the initial storage of the involute coordinates.

I. Program LEWIS CIRCLES (See Appendix G)

a. Dimensioning of Arrays

(For more details on the use of the various arrays see description of computations below).

The vectors X1 and Y1 are used for the initial storage of the involute coordinates of the gear tooth (see Appendix A). The minimum number N_{Y1} of locations for either of these arrays is given by: (See also Appendix F)

$$N_{Y1} = \frac{\alpha_{fin} - \alpha_{in}}{\Delta\alpha} \qquad (1)$$

where

α_{in} = initial involute generating angle [See equ. (D23) of Appendix D].

α_{fin} = final involute generating angle [See equ. (D24)].

$\Delta\alpha$ = increment of involute generating angle.

The arrays X2 and Y2 are used for the final storage of all values of the tooth profile coordinates. The required number of locations is represented by the sum of those needed for the vectors Y1 (or X1) and Y. It can only be determined once the length of the vector Y is known. The later is obtained with the help of the aforementioned program MATRIX, which also finds the size of matrix X.

b.   Input Parameters

The following parameters represent the required input data for the program. (They are also printed out on top of the first output page).

N = number of teeth in gear under consideration

BEFF = b_{eff} for unity diametral pitch (See Appendix B)

PD = P_d = 1.000, unity diametral pitch of hob

THETAD = θ, the pressure angle of the hob (the D at the end expresses that an angle is given in degrees)

CAPTCS = T_{cs}, the circular tooth thickness of the gear at the standard pitch radius $R_p = \frac{N}{2P_d}$, in terms of P_d = 1.000

RC = r_c, the rack fillet radius for unity diametral pitch

KADD = Addendum constant of gear, with the magnitude of the addendum defined by KADD/PD , in terms of P_d = 1.000

DELPSI = $\Delta\psi$, the increment of the roll angle of the rack pitchline on the pitch circle of the gear (See note below)

DELAL = $\Delta\alpha$, the increment of the involute generating angle(See note below)

CONB = Initial value of constant B of Lewis parabola[See equ. (E32)]

DELCON = ΔB, the increment of the constant B of the Lewis parabola (See note below)

NRITE = Test constant. When NRITE = 1, all the tooth profile coordinates stored in X2 and Y2 are printed out. These coordinates are not printed out when NRITE = 0.

NOTE: The choice of the magnitudes of $\Delta\alpha$, $\Delta\psi$ and ΔB is discussed in Section 3.

c. Computations

Starting with line 29 of the program each location of the matrix X is filled with the value -10.00. This is necessary, since the subsequent sorting process must determine the largest value in rows whose locations are either unfilled or contain negative numbers. If such an unfilled location contains a zero, it will be found as the answer rather than the actual x-coordinate of the left root profile.

Subsequent to line 33 various gear parameters, such as the pitch radius R_p, the base radius R_b and the outside radius R_o are computed. Further, the following quantities are determined:

B = b_{eff} = $\frac{BEFF}{PD}$, the actual distance to the effective point for the given diametral pitch

THETAB = θ_b, see equ. (A1)

The later is computed with the help of the involutomery formula given by equ. (E16) of Appendix E. For this case:

$$T_1 = T_{cs}\ , \quad R_1 = R_p\ , \quad \phi_1 = \theta$$

and

$$T_2 = T_b\ , \quad R_2 = R_b\ , \quad \phi_2 = 0$$

so that

$$T_b = T_{cs}\frac{R_p \cos\theta}{R_p} - 2R_b\ [\ \mathrm{INV}\ (0) - \mathrm{INV}\ (\theta)]$$

or

$$T_b = T_{cs}\cos\theta + 2R_b\ [\ \tan\ (\theta) - \theta\ ]$$

and finally,

$$\theta_b = \frac{T_b}{R_b} = \frac{T_{cs}\cos\theta}{R_b} + 2(\ \tan\theta - \theta\ ) \qquad (2)$$

Following line 41 one finds:

EPS $= \frac{\theta_b}{2} + \theta$, for use in equ's. (B8) and (B9)

DELTA $= \frac{b_{eff}}{R_b \sin\theta} - \tan\theta$, see equ. (B22)

BALLOW $= b_{effmax}$, according to equ. (B1)

Lines 45-47 represent a test which decides with the help of equ. (B1) whether or not the tooth is undercut.

Lines 48-60 are applicable for undercut teeth. The following computations are performed:

A = a, according to equ. (B 2)

TAU = EPS, from line 42

The inner form radius RF = R_f is obtained with the help of equ. (D 9). This non-linear algebraic equation is solved by subroutine DEKKER. The radii R_o and R_b represent the limit within which the root R_f is determined.

ALPHIN = α_{in}, according to equ. (D23)

ALPHF = α_{fin}, according to equ. (D24)

GAMT = γ_{tot}, according to equ. (D16)

PSIIN = ψ_{in}, according to equ. (D18)

PSIF = ψ_{fin}, according to equ. (D14)

Lines 62 to 82 are applicable to teeth which are not undercut. The essential computations are given by:

A = a, according to equ. (B10)

TAU = EPS + DELTA, from lines 42 and 43 [*This is η in equ's. (B22), (B24) and (B25)*]

RF = R_f, according to equ. (D12)

GAMT = γ_{tot}, according to equ. (D16) with the above RF

ALPHIN = α_{in}, according to equ. (D23). The test for α_{in} has the purpose of avoiding an almost zero number when a zero should be obtained

ALPHF = α_{fin}, according to equ. (D24) with the RF of line 66

PSIIN = 0, according to equ. (D20)

PSIF = ψ_{fin}, according to equ. (D19)

The computations represented by lines 82 to 88 are applicable to both types of teeth. In addition to converting certain angles from radians to degrees for printing out, the following parameters of the center of the rack fillet are computed:

A2 = a_2, according to equ. (C1)

B2 = b_2, according to equ. (C2)

Lines 89 to 104 concern themselves with the determination of the coordinates of the involute portion of the tooth. It is at first most convenient to store XI = x_{inv} and YI = y_{inv}, which are obtained from equations (A5) and (A6), respectively, in the vectors X1(I) and Y1(I). For I = 1, the angle $\alpha = \alpha_{in}$. When this counter has attained its maximum value, the angle α is just a little larger than α_{fin}. Note also that this maximum value of the counter I is stored as IPREV for future use. For purposes of subsequent computations it is desirable to have the counter of the coordinate locations of the tooth profile start at the tip of the tooth and end at that root location which corresponds to ψ_{fin}. For this reason, the sequence of the involute coordinate counter is inverted in the operations of lines 100 to 103. These coordinates are now stored in the vectors X2 and Y2. (Note that the counter number corresponding to IPREV now denotes the location of the involute coordinates associated with the angle α_{in}).

The determination of the coordinates of the tooth root, i.e. the trochoid, starts in line 105. Initially, the vector Y(I) and the matrix X(I,J) are created in the manner described in Appendix C-2. Subsequently, a search procedure determines the largest value of the x-coordinate X2 associated with a given y-coordinate Y2. It is to be recalled that, the parameters appropriate to the type of tooth under consideration have already been stored and that, therefore the same basic expressions can be used in the program whether the tooth is undercut or not.

The following explains the manner in which the program fills the vector Y(I) and the matrix X(I,J):

(1) The angle ψ is made equal to ψ_{in} and the counter I, for the y-coordinate, and the counter J, for the number of the circle, are initialized.

(2) Starting with location 25 (line 111), the fillet center coordinates XC = x_c and YC = y_c are computed according to equ's. (C3) and (C4) or equations (C5) and (C6). Further, the y-coordinate YT = y_{tr} of the effective point of the rack is obtained with the help of equ. (B9) or

equ. (B25). If these computations were made for the first position of the fillet circle, i.e. for J = 1 (in the program I = 1 is used), control is transferred to location 80.

(3) Starting with location 80, the value for YT is multiplied by 1000 and the result is truncated such that the integer IYT results. This operation, which in essence multiplies a y-coordinate given to one one thousandth of an inch by 1000, is necessary for subsequent identification purposes. In addition, IYT is stored in vector Y(I) in location 90. (Thus, rather than storing the actual y-coordinate its thousand-fold value is used). If the the effective point of the first circle is involved, I = 1. With the above accomplished, IYT is again made into a real number and divided by 1000 (giving the y-coordinate to the nearest one one thousandth of an inch) for further work. It is now labelled YTTT [The y of equ. (C7)]. In order to be able to stop the computations for points on a given fillet circle, once

$$y \leq y_c - r_c , \qquad (3)$$

the test of lines 127 and 128 has been devised. The x-coordinate associated with YTTT is then obtained with the help of equ. (C9) of Appendix C and stored in X(I,J), where J is the circle number and I is the counter of the y-coordinate. This sequence, which starts on line 124 and ends with line 132 is continued until the limit of equ. (3) is reached for a given circle. In each step the counter I is incremented by 1, the integer IYT is decreased by 1 and stored in Y(I), and finally the associated x-coordinate is stored in the appropriate X(I,J). When the computations for any fillet circle are completed, control is transferred to location 150.

(4) Starting with location 150, the stage is set to compute the x and y coordinates of points on subsequent circles: The angle ψ is decremented by $\Delta\psi$, and a test is made to check whether ψ_{fin} has been reached. In addition, the circle counter J is incremented by 1 as long as $\psi < \psi_{fin}$. To obtain the data for a new circle, control is transferred to location 25 again. In case the limiting angle ψ_{fin} has been reached, the value J corresponding to the last circle is stored as JFIN, and control is given to location 500 to commence the search for the largest value of X(I,J) in a given row of the array.

(5) If control was transferred to location 25, the steps described in (2) above are repeated for the new position of the fillet circle. In order to be able to form an array

as shown in Table C-1 of Appendix C, it is necessary to establish that location Y(I) of any previous circle which contains an IYT of the same magnitude as that which corresponds to the effective point of the new circle.

This is accomplished by the sorting procedure starting in line 115 and ending in line 121: The counter I, which serves to call on the already existing Y(I), is initialized and YT is made into the integer IYT. The desired location Y(I) is found by comparing the content of each of the existing Y(I) with the value of the above IYT. When the test

$$Y(I) - IYT \leq 0 \tag{4}$$

is met, control is transferred to location 90 and the present values of I and IYT are reestablished as the counter and the content of this Y(I).

At this point all operations for a given circle may be performed as described beginning with the second paragraph of section (3) above.

(6) As stated earlier, once all the possible Y(I) and X(I,J) are filled, control is transferred to location 500 to

search for the x-coordinates of the root profile.

The preparation for the determination of the largest value of X(I,J) corresponding to any y-coordinate Y(I) starts in location 500 (line 139). YFIN, the smallest value of the y-coordinate for which X(I,J) has been found earlier, is obtained by way of YCFIN. This variable is obtained with the help of the fillet center expressions (C4) or (C6), evaluated at $\psi = \psi_{fin}$. Then, similar to equ. (3):

$$YFIN = YCFIN - RC \tag{5}$$

Subsequently, the following operations are performed:

(1). The counter I is initialized. It is used to keep track of the Y(I) and X(I,J) of before.

(2). The counter K = I + IPREV is introduced in location 501. This counter makes it possible to add the final values of the root coordinates to vectors X2 and Y2, which presently only contain the involute coordinates in locations from I = 1 to I = IPREV. (See line 98).

(3). KFIN = K is introduced, in order to be able to label the last values of X2 and Y2.

(4). The sorting process for each row of the array X(I,J) starts in line 144 with the initialization of X2(K) = -10.00. The loop between line 145 and 147 starts by comparing the above value with that of the content of X(1,1) i.e. the first value in the first row. If X(1,1) is larger than -10.00, X2(K) is made equal to X(1,1). If it contains the initially read-in value of -10.00, X2(K) remains as -10.00 (See line 31). In the next comparison, the content of X(1,2) is compared with the current value of X2(K). In case X(1,2) > X2(K) , this value of X(1,2) is made the current value of X2(K). This sorting process is repeated until J = JFIN , the number of the last fillet circle (See line 137).

(5). The outer loop of the sorting process includes lines 142 to 151. Once the largest value of any row of X(I,J) has been stored in X2(K), the content of the associated Y(I) is divided by 1000.00 and stored in Y2(K). This operation is repeated until the last value of Y2 becomes equal to or smaller than the previously determined YFIN.

Control is transferred to location 21, whenever the vectors X2 and Y2 contain a complete set of coordinates for the left tooth profile.

The determination of the various parameters, needed for the computation of the Lewis factor, starts in location 21 with the following:

PHIRO = ϕ_{R_o} , according to equ. (E22)

BETA = β , according to equ's. (E21)

THETAO = θ_{R_o} , see equ. (E29)

RV = R_v , according to equ. (E28)

The search for the point of tangency between the Lewis parabola and the tooth profile is conducted according to the outline in Appendix E-4. It is first necessary to find the value of the counter K, used in X2(K) and Y2(K), which corresponds to that of the y-coordinate RV of point V of Figure E-4. The range between this point and the already known YFIN, for which K = KFIN, is the range in which the tangency will occur.

For computational reasons, the point START rather than point V is chosen. Thus,

$$\text{START} = \text{RV} - .005 \text{ (inches)} \qquad (6)$$

The location of that Y2 which corresponds to START is found in the loop between lines 165 and 169. Once the number of this location is found, it is labelled BEGIN.

The determination of the tangency point is carried out in the loop between lines 172 and 179. Using the counter J, the value of K is varied between

$$K = \text{BEGIN} + J - 1 \qquad (7)$$

and

$$K = \text{BEGIN} + \text{KFIN} - 1 \,, \qquad (8)$$

where KFIN is the difference between the KFIN of line 143 and BEGIN of line 170.

The operation consists of the following steps:

(1). The value of XPAR = x_{par} is computed according to equ. (E32), using the initial value of CONB = B [See equ. (E31)], for the full range of values of Y2(K). In each step, the difference

$$DIFF2 = |X2(K)| - XPAR \tag{9}$$

is computed [See also equ. (E33)]. If this difference is less than or equal to zero, the point of tangency has been found and control is transferred to location 109 (line 180).

(2). If the point of tangency cannot be found for a given value of CONB, this value is decremented by DELCON (see line 178) and equ. (9) is used to test a new series of XPAR values. This process is continued until the values of X2(K) and Y2(K), associated with the tangency point, are found.

Finally, with $X2(K_{tan})$ and $Y2(K_{tan})$ found, EX = x is computed according to equ. (E35), and the Lewis factor as well as the AGMA geometry factor are determined with the help of equ's. (E11) and (E36), respectively.

d. Output Parameters

(All lengths are given in inches and all angles in degrees).

The output of the program first states the numerical values of the input parameters N, BEFF, PD, THETAD, CAPTCS, RC, KADD, DELAL, DELPSI, DELCON and CONB. Subsequently, it is stated whether or not the tooth is undercut. In addition, the output gives numerical values for the following quantities:

RP = $R_p = \frac{N}{2\ P_d}$, the pitch radius of the gear

RB = $R_p \cos\theta$, the base radius of the gear

RO = $R_p + \frac{KADD}{P_d}$, the outside radius of the gear

RF = R_f , the inner form radius, either according to equ. (D9), or according to equ. (D12)

EPS = $\frac{\theta_b}{2} + \theta$, in degrees

THETAB = θ_b , according to equ. (2), in degrees

DELTA = $\frac{b_{eff}}{R_b \sin\theta} - \tan\theta$, according to equ. (B22), in degrees

TAU	=	EPS or EPS + DELTA
GAMT	=	γ_{tot} , according to equ. (D16)
ALPHIN	=	α_{in} , according to equ. (D23)
ALPHFIN	=	α_{fin} , according to equ. (D24)
PSIIN	=	ψ_{in} , according to equ. (D18) or equ. (D20)
PSIFIN	=	ψ_{fin} , according to equ. (D14) or equ. (D19)
PHIRO	=	ϕ_{R_o} , according to equ. (E22)
BETA	=	β , according to equ's. (E21)
CAPTO	=	T_o , tooth thickness at R_o, computed according to equ. (E16)
THETAO	=	θ_{R_o} , computed according to equation (E15) and furnishing a result identical to that of equ. (E29)
RV	=	R_v , according to equ. (E28)

EX	=	x , according to equ. (E35)
YLEWIS	=	Y , the Lewis factor, according to equ. (E11)
YAGMA	=	Y_{AGMA} , according to equ. (E36)
TANGENCY K	=	value of counter K at point of tangency between Lewis parabola and tooth profile
Y2(KTAN)	=	y-coordinate of tooth profile associated with point of tangency
X2(KTAN)	=	x-coordinate of tooth profile associated with point of tangency
XPAR TAN	=	x-coordinate of parabola associated with point of tangency
CONB	=	final value of constant B of Lewis parabola
NRITE	=	Test constant (see section b above)

If NRITE = 1, the program causes the printing of the tooth profile coordinates Y2(K) and X2(K) for all values of K, starting from the tip of the tooth down towards its root. The transition from the involute to the trochoidal part of the profile occurs where the values of Y2(K) are given to one one-thousandth of an inch. Recall that, since the program computes the left tooth profile, the values of X2(K) are negative.

II. Program LEWIS ENVELOPE (See Appendix H)

a. Dimensioning of Arrays

Again, the vectors X1 and Y1 are used for the initial storage of the involute coordinates of the gear tooth. The sizes of these vectors are also determined with the help of equ. (1), or by way of program MATRIX (see Appendix F).

The vectors X2 and Y2 must again hold the values of the involute coordinates as well as those of the root coordinates. The required dimensions of these arrays may be obtained by adding the number of rows of vector Y1 to the following number of trochoid computation intervals:*

$$N_{t_r} = \frac{\psi_{in} - \psi_{fin}}{\Delta\psi} \quad \text{(see below)} \qquad (10)$$

where

ψ_{in} = initial trochoid generating angle [For undercut teeth use equ. (D18), for non-undercut teeth equ. (D20) is

* *The number of these intervals is identical with the column number for the tooth root interval, as given in the output of program MATRIX in Appendix F. See also equ. (F8).*

applicable. ψ_{in} is positive or zero.]

ψ_{fin} = final trochoid generating angle. [For undercut teeth use equ. (D14), for non-undercut teeth use equ. (D19). ψ_{fin} is always negative. This explains the form of equ. (10).]

$\Delta\psi$ = increment of roll angle of the rack pitch line (See earlier.)

b. Input Parameters

The input parameters for program LEWIS ENVELOPE are the same as those for program LEWIS CIRCLES.

c. Computations

With the exception that MATRIX X does not exist in this program, LEWIS ENVELOPE is parallel to LEWIS CIRCLES up to line 98: Various initial gear parameters are computed. It is decided whether or not the gear tooth is undercut and the associated parameters are determined. The involute coordinates are computed and stored in vectors X1 and Y1, with the last computation corresponding to the outside radius of the tooth. In order to be able to obtain tooth profile coordinates which start with the tip of the tooth, the order of the vectors X1 and Y1 is again reversed and the result is stored in the vectors X2 and Y2. The location number of the last pair of involute coordinates (now associated with the angle α_{in}) corresponds again to the value of IPREV.

The determination of the tooth root coordinates starts in line 99 and proceeds in the following manner:

(1) The angle ψ is made equal to ψ_{in}, and the counter I is initialized at

$$I = IPREV + 1 \tag{11}$$

(2) A loop, starting with line 104 and ending with line 112, computes the coordinates XENV = x_{env} and YENV = y_{env} according to equ's. (C21) and (C22), respectively, until $\psi = \psi_{fin}$ (PSIFD). The results are stored in vectors X2 and Y2, between the locations I = IPREV + 1 and I = KFIN.

The computations for the LEWIS and AGMA factors start in line 114 (statement no. 21) and are identical to those of program LEWIS CIRCLES up to and including line 151.

d. Output Parameters

The output parameters of program LEWIS ENVELOPE are identical to those of program LEWIS CIRCLES. The print-out of the tooth profile coordinates differs from that in program LEWIS CIRCLES somewhat. For the present case, it was possible to separate the involute coordinates from the trochoid coordinates by appropriate headings, i.e. INVOLUTE PLOT and TROCHIOD PLOT.

3. SAMPLE RUNS OF PROGRAM LEWIS CIRCLES AND LEWIS ENVELOPE

This section first discusses the results of two identical sample runs which were made with each of the two programs. The first type of run involves a non-undercut 36 tooth gear. The second concerns itself with an undercut 12 tooth pinion.

Appendix G lists program LEWIS CIRCLES on pages G-2 to G-9. The associated output for the 36 tooth gear is given on pages G-10 to G-18, while that for the 12 tooth pinion covers pages G-19 to G-37.

Appendix H lists program LEWIS ENVELOPE on pages H-2 to H-9. The associated output for the 36 tooth gear is given on pages H-10 to H-14. There are two outputs for the 12 tooth pinion. The one with the larger angle increment $\Delta\psi$ is given on pages H-15 to H-19, while that for the smaller increment $\Delta\psi$ is reproduced on pages H-20 to H-32. Finally, the results of certain selected computations of LEWIS and AGMA factors are given in tabular form.

I. Sample Runs of Program LEWIS CIRCLES

a. 36 Tooth Gear

1. Input Parameters (See also Section 2-Ib)

With one exception, all input data of this run are printed out on top of the first output page (See p. G-10).

N	=	36 teeth
BEFF	=	1.215 in.
PD	=	1.0, diametral pitch
THETAD	=	20 degrees
CAPTCS	=	1.846 in.
RC	=	.04 in.
KADD	=	1.425 in.
DELAL	=	.250 degrees
DELPSI	=	.125 degrees
CONB	=	4.0
DELCON	=	.001

Further, on the bottom of the first output page:

NRITE = 1

2. Array Dimensions

The output of the program MATRIX on p. F-12 gives the following minimum dimensions for the various arrays associated with the 36 tooth gear:

Length of rows for involute vectors X1 and Y1:	94
Length of rows and columns for tooth root arrays:	ROW = 370, COL = 85
This leads to the minimum number of locations for vectors X2 and Y2:	94 + 370 = 464

As a consequence of the above, the following dimension statements are included in the program of this run (see p. G-2):

X1(100), Y1(100)
Y(400) , X(400, 100)
X2(500), Y2(500)

3. Output Data (See also Section 2-Id)

The first output statement on page G-10 conveys the fact that the "TOOTH IS NOT UNDERCUT". The subsequent data block is useful for checking purposes:

RP	=	18.000 in.
RB	=	16.91447 in.
RO	=	19.425 in.
RF	=	17.11373 in.
THETAB	=	7.58392 degrees
GAMT	=	0.0 degrees
EPS	=	23.79196 degrees
DELTA	=	-8.82052 degrees
TAU	=	14.97144 degrees
ALPHIN	=	8.82052 degrees
ALPHFIN	=	32.35465 degrees
PSIIN	=	0.0 degrees
PSIFIN	=	-10.6258 degrees

PSIRO = 29.4532 degrees (This is actually PHIRO acc. to Section 2-Id)

BETA = 28.56269 degrees

CAPTO = .60383 in.

THETAO = .89052 degrees

RV = 19.25831 in.

The first line of the lowest block of results on page G-10 deals with the essential output of the program, i.e.:

EX = .55278 in., the Lewis dimension x

YLEWIS = .3685, the Lewis factor

YAGMA = .36221, the AGMA geometry factor

The second line of this data block gives further values which are of interest for checking purposes:

TANGENCY K = 237, i.e the point of tangency between the tooth profile and the Lewis parabola was found by the program to occur at Y2(237)

Y2(KTAN) = 16.937 in. , y-coordinate of tooth profile at point of tangency.

X2(KTAN)	=	-1.13277 in., x-coordinate of tooth profile at point tangency
XPAR TAN	=	1.132784 in., absolute value of x-coordinate of Lewis parabola at point of tangency
CONB	=	1.809, final value of constant B of Lewis parabola

The listing of the coordinates of the left tooth profile, i.e. of the values stored in the associated vectors X2 and Y2, begins on top of page G-11. Recall that the values of these coordinates are printed out in such a way that they start at the tip of the tooth and end at its root. The involute portion of the profile begins with K = 1 and ends with K = 96. While the first set of values of the trochoidal portion of the tooth profile at K = 97 is not specifically marked, it may be recognized by the fact that Y2(97) represents the first y-coordinate which is given in terms of one one-thousandth of an inch. This trochoidal portion of the profile ends with K = 460. Note that the point of tangency at K = 237, is well above the last point of the profile.

b. <u>12 Tooth Pinion</u>
(Appendix G shows only the output of this run.)

1. Input Parameters

With the exception of the NRITE statement, all input data are printed again on top of page G-19:

N	=	12
BEFF	=	1.0526 in.
PD	=	1
THETAD	=	20 degrees
CAPTCS	=	1.57079 in.
RC	=	.300 in.
KADD	=	1.000 in.
DELAL	=	.250 degrees
DELPSI	=	.500 degrees
CONB	=	4.0
DELCON	=	.001

Further, as shown on the botton of page G-19:

NRITE	=	1

2. Array Dimensions

(The program listing containing the dimension statement given below is not reproduced in this report.)

The output of program MATRIX on page F-13 gives the following minimum array dimensions for the given pinion data (For rationale, see parallel section for the 36 tooth gear.).

X1(150) , Y1(150)
Y(995) , X(995, 52)
X2(1145), Y2(1145)

3. Output Data

The first output statement on p. G-19 indicates that the "TOOTH IS UNDERCUT". The subsequent data block may be interpreted as discussed in section 2-Id and is parallel to the one shown for the 36 tooth gear. The first line of the lowest block of results again represents the essential output of the run, i.e.:

EX = .34446 in., the Lewis dimension x

YLEWIS = .22964 , the Lewis factor

YAGMA = .2364 , the AGMA geometry factor

The second line of this data block gives:

TANGENCY K = 729

Y2(KTAN) = 5.019 in.

X2(KTAN) = - .780016 in.

XPAR TAN = .78003 in.

CONB = 2.903

The listing of the tooth profile starts on p. G-20. The involute portion of the tooth profile begins with K = 1 and ends with K = 152. The trochoidal part of the profile extends from K = 153 to K = 1133. Note that the point of tangency, at K = 729, is well above the last computed profile point.

II. Sample Runs with Program LEWIS ENVELOPE

a. 36 Tooth Gear

1. Input Parameters

With the exception of CONB = 5.0, the input parameters of this run with program LEWIS ENVELOPE are identical with those used in the run with program LEWIS CIRCLES (See section 3-Ia). As before, these data are listed principally on top of the first output page of the program. This output page is reproduced on p. H-10 of this report. (Note that the format of the first output page of program LEWIS ENVELOPE is the same as that of the first output page of program LEWIS CIRCLES.)

2. <u>Array Dimensions</u>

A certain part of the results of program MATRIX may be used to determine the dimensions of the vectors X1 and Y1 as well as those of the vectors X2 and Y2. Thus, from p. F-12:

Length of rows for involute vectors X1 and Y1: 94

Since there is now one set of root profile coordinates for each position of the angle ψ, the number of rows of these coordinates is equal to the number of columns given by program MATRIX under the heading of "Number of rows and columns for tooth root arrays". [See equ's. (10) and (F8)]. Thus, the number of root coordinate pairs equals 85 according to p. F-12.

The minimum dimensions for X2 and Y2 then become : 94 + 85 = 179. Actually, the following larger dimensions were included into the program for this run (see program LEWIS ENVELOPE on p. H-3):

X1(180) , Y1(180)

X2(1000), Y2(1000)

3. Output Data

The central output data block, starting with "TOOTH IS NOT UNDERCUT" and ending with RV = 19.25831 is identical with that obtained by way of program LEWIS CIRCLES, as shown on p. G-10. The first line of the lowest output data block again furnishes the principal results of the run. (Recall that the root profile coordinates are computed in a different manner in program LEWIS ENVELOPE.) Thus,

EX	=	.55277 in.
YLEWIS	=	.36851
YAGMA	=	.36221

These results are identical with those obtained by way of program LEWIS CIRCLES. The second line of this lowest block is useful for comparison purposes (see Section 4):

TANGENCY K	=	117
Y2(KTAN)	=	16.93642 in.
X2(KTAN)	=	-1.132901 in.
XPAR TAN	=	1.132924 in.
CONB	=	1.809

The listing of the tooth profile coordinates starts on top of page H-11. As for the comparable run with program LEWIS CIRCLES, the involute portion of the profile is given from K = 1 to K = 96. The root part of the profile extends from K = 97 to K = 182.

b. 12 Tooth Pinion

Program LEWIS ENVELOPE was run twice for the 12 tooth pinion. The input data of the first run are identical with those used earlier in conjunction with program LEWIS CIRCLES (See section 3-Ib). In the second run the increment $\Delta\psi$ was reduced to .05 degrees in order to observe the influence of the more closely spaced y-coordinates of the root profile.

1. Input Parameters for Run with $\Delta\psi$ = .5 degrees

The input data for this run, as shown on p. H-15, are the same as those given in section 3-Ib1.

2. Array Dimensions for Run with $\Delta\psi$ = .5 degrees

The minimum array dimensions for this run may again be obtained in the manner discussed in section II-a2 above with the help of the results of program MATRIX on p. F-13.

Since the lengths of the rows of involute vectors X1 and Y1 must be at least 150,

X1(150) , Y1(150)

The number of columns for the root array X of program LEWIS CIRCLES was determined to be 52. Therefore,

X2(202) , Y2(202)

3. Output Data for Run with $\Delta\psi$ = .5 degrees

The central output data block of p. H-15 is identical with that obtained from program LEWIS CIRCLES (see page G-19). The principal results, as given in the lowest output block, are as follows:

EX	=	.34443 in.
YLEWIS	=	.22962
YAGMA	=	.23643
TANGENCY K	=	177
Y2(KTAN)	=	5.01112 in.

X2(KTAN)	=	-.781767 in.
XPAR TAN	=	.781767 in.
CONB	=	2.903

These results are essentially identical with those obtained from program LEWIS CIRCLES. The difference in the y-coordinate of the tangency point is due to the different manner of computing the tooth root coordinates. (See discussion in section 4 below.) The listing of all tooth profile coordinates is given on pp. H-16 to H-19 of Appendix H.

4. Output Data for Run with $\Delta\psi$ = .05 degrees

The input/output data of this run with a reduced angular increment are listed on pp. H-20 to H-32 of Appendix H. The principal results are as follows:

EX	=	.34447 in.
YLEWIS	=	.22965
YAGMA	=	.23635
TANGENCY K	=	385

N	BEFF (in.)	CAPTCS (in.)	RC (in.)	KADD (in.)	Lewis Factor	AGMA Factor
12	1.000	1.57079	.239	1.000	.24189	.24807
13	"	"	"	"	.25493	.25922
24	"	"	"	"	.33822	.32876
30	"	"	"	"	.36134	.34784
45	"	"	"	"	.39494	.37542
50	"	"	"	"	.40209	.38121
100	"	"	"	"	.43683	.40976
300	"	"	"	"	.45828	.42337
12	.800	1.57079	.304	.800	.33517	.32598
13	"	"	"	"	.34831	.33712
15	"	"	"	"	.37016	.35521
45	"	"	"	"	.47858	.44417
300	"	"	"	"	.53370	.48946
12	1.0526	1.57079	.300	1.000	.22964	.23640
13	"	"	"	"	.24321	.24817

(For all runs: Diametral pitch is unity and hob pressure angle is 20°. All runs made with program LEWIS CIRCLES.)

Table 1

Selected Computations of Lewis and AGMA Geometry Factors

Y2(KTAN) = 5.02859 in.

X2(KTAN) = -.777906 in.

XPAR TAN = .777909 in.

CONB = 2.903

III. Selected Computations of the Lewis and the AGMA Geometry Factors

Table 1 shows the results of selected determinations of the Lewis and the AGMA geometry factors. In all cases, the computations were made with the help of program LEWIS CIRCLES and a diametral pitch of one, together with a 20 degree hob pressure angle were used.

4. DISCUSSION

This section first presents a discussion of certain differences in the results for the two sample gears of section 3, as obtained with programs LEWIS CIRCLES and LEWIS ENVELOPE. (Table 2 juxtaposes the essentials of these results.)

Subsequently, a number of special features and peculiarities of both programs are pointed out.

I. Comparison of Results for 36 Tooth Gear and 12 Tooth Pinion

When comparing the results of the two programs for a given set of data, it must be kept in mind that the point of tangency of the Lewis parabola is generally located in the root portion of the tooth profile and that the programs produce the root profile in different ways.

Program	N	YLEWIS	YAGMA	Y2(KTAN) (inches)	X2(KTAN) (inches)	XPAR TAN (inches)	CONB
CIRCLES $\Delta\psi = .125$	36	.36852	.3622	16.937	1.13277	1.13278	1.809
ENVELOPE $\Delta\psi = .125$	36	.36851	.36221	16.9364	1.13290	1.13292	1.809
CIRCLES $\Delta\psi = .500$	12	.22964	.23640	5.0190	0.78002	0.78003	2.903
ENVELOPE $\Delta\psi = .500$	12	.22962	.23643	5.0111	0.78173	0.78177	2.903
ENVELOPE $\Delta\psi = .050$	12	.22965	.23635	5.0286	0.77791	0.77791	2.903

Table 2

Comparisons of Results of Programs

LEWIS CIRCLES and LEWIS ENVELOPE

Program LEWIS CIRCLES furnishes one x-coordinate of the tooth root for every one one-thousandth of an inch of the y-coordinate. The accuracy of these x-coordinates improves as the increment $\Delta\psi$ is made smaller, i.e. as more circles become involved in this simulation of the drafting process. (See Appendix C-2.)

Program LEWIS ENVELOPE produces accurate x-coordinates of the root profile, because of its analytical origin. To obtain these x-coordinates in one one-thousandth of an inch increments, the increment $\Delta\psi$ has to be quite small.

Let the results in Table 2 for the 36 tooth gear be compared first: Both sets of results were obtained with $\Delta\psi$ = .125, and they are essentially identical. The spacing of the y-coordinates due to program LEWIS ENVELOPE may be seen on p. H-13 of Appendix H. The point of tangency is at Y2(117) = 16.9364 in. The preceding as well as the succeding values of the y-coordinates are approximately .006 inches away. Because of the magnitude of these distances, it is probably fortuitous that such close agreement could be obtained.

While the results for the Lewis and AGMA factors as well as for the constant B are also essentially identical in the case of the 12 tooth pinion, there are some small differences in the x and y-coordinates of the root profiles. Even though the increment $\Delta\psi$ = .500 is quite large, it had to be used in running program LEWIS CIRCLES, since the associated array X already had a 995 x 52 dimension and with that required a very large amount of computer core. (See output of program MATRIX on p. F-13.) When this increment was used to run program LEWIS ENVELOPE, the magnitude of the spacing of the y-coordinates near the point of tangency was approximately .020 inches. (See K = 177 on p. H-19.)

When program LEWIS ENVELOPE was run with $\Delta\psi$ = .05. the spacing of the y-cooridnates surrounding the point of tangency was of the order of .002 inches (See K = 385 on p. H-27.). This result appears to be the best of the three.

Aside form these small discrepancies, both programs furnish excellent results.

II <u>Special Features of Program LEWIS CIRCLES</u>

a. All input data must be expressed in terms of unity diametral pitch.

b. The program cannot be run for a hob fillet radius RC = 0, since its simulation of the drafting process requires such a radius. This limitation can be overcome by choosing a very small radius for the case of a sharp cornered hob. (By letting RC = .040 in. for the unity diametral pitch computation, an actual gear of 60 diametral pitch will be cut by a cutter with a radius of .00067 in.)

c. The angular increment $\Delta\alpha$ must be chosen sufficiently small if one desires a fairly close spacing of the y-coordinates of the involute part of the tooth profile for drawing purposes. A $\Delta\alpha$ = .25 degrees caused a spacing of between .015 and .030 inches for the 36 tooth gear and a spacing of between .003 and .015 inches for the 12 tooth pinion. The larger spacing will always occur near the tip of the tooth.

d. The choice of the root angular increment is especially important. The smaller $\Delta\psi$, the larger the number of circles for a given y-coordinate of the root region, and with that the greater the accuracy of the resulting root profile. This becomes crucial when the hob fillet radius RC is small. For RC = .040 in. an increment $\Delta\psi$ = .125 degrees gave good results. With RC = .300 in., the increment $\Delta\psi$ = .500 deg. was satisfactory. (There is a trade-off between accuracy and core space requirement.)

Because the number of overlapping circles decreases near the bottom of the root profile, it is a good idea to check whether the y-coordinate of the point of tangency is at least one quarter of the magnitude of the hob fillet radius away from the final y-coordinate of the root profile. If this is not the case, it is best to diminish the angle PSIFIN, i.e. continue further with the drafting simulation. (The above serves only as a cautionary note, since during all trial runs the point of tangency was well away from the end of the tooth root.)

e. Since the root profile coordinates are stored at

.001 inch intervals of the y-coordinate, the point of tangency will be accurate as long as the root profile is accurate.

III. Special Feature of Program LEWIS ENVELOPE

a. All input data must also be expressed in terms of unity diametral pitch

b. The program can be run for all values of the hob fillet radius, including RC = 0.

c. The above remarks concerning the angular increment $\Delta\alpha$ also apply here.

d. While the y-coordinates of the root portion of the tooth profile are given at intervals of .001 in. by program LEWIS CIRCLES, the spacing of these coordinates by program LEWIS ENVELOPE depends entirely on the magnitude of the angular increment $\Delta\psi$. If this increment is too large, the y-coordinates of the root profile may have a fairly wide spacing.

Since the point of tangency of the Lewis parabola can only be found for existing y-coordinates, this point will only then be accurately determined if the spacing of these coordinates is of the order of .001 inches. Since there is no core problem with program LEWIS ENVELOPE, $\Delta\psi \leq .05$ degrees can readily be used.

APPENDIX A

DETERMINATION OF INVOLUTE COORDINATES

Figure A-1 shows an involute gear tooth, originating at its base circle, in the standard vertical position as defined for this report.

It is assumed that the circular tooth thickness $t_b = \overline{VV'}$ at the base circle and the associated angle θ_b are known. To determine the x and y coordinates of the arbitrary point T on the involute, the unit vectors $\bar{n}_{ou}$ and $\bar{n}_{ut}$, in directions $\overline{OU}$ and $\overline{UT}$, respectively, must first be determined. Thus,

$$\bar{n}_{ou} = \cos(90 + \frac{\theta_b}{2} - \alpha)\ \bar{i} + \sin(90 + \frac{\theta_b}{2} - \alpha)\ \bar{j} \qquad \text{(A1)}$$

where

α = the roll angle of the generating tangent $\overline{UT}$

$\theta_b = \dfrac{t_b}{R_b}$, where R_b represents the base radius

Equation (A1) may be simplified to:

$$\bar{n}_{ou} = -\sin(\frac{\theta_b}{2} - \alpha)\ i + \cos(\frac{\theta_b}{2} - \alpha)\ \bar{j} \qquad \text{(A2)}$$

The unit vector $\bar{n}_{ut}$ is found by cross multiplication of $\bar{n}_{ou}$ by the unit vector $\bar{k}$:

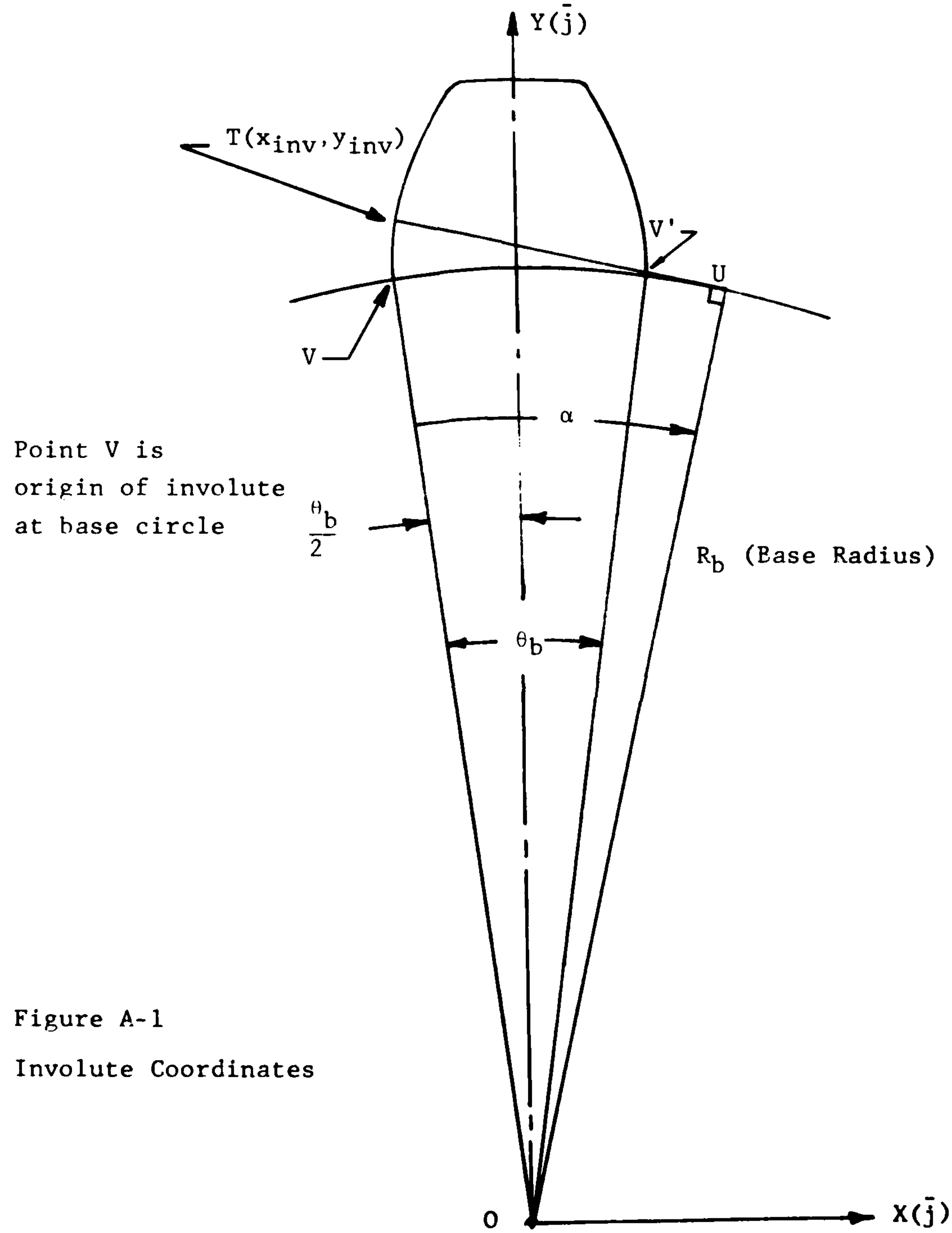


Figure A-1

Involute Coordinates

$$\bar{n}_{ut} = \bar{k} \times \bar{n}_{ou} = -\cos\left(\frac{\theta_b}{2} - \alpha\right) \bar{i} - \sin\left(\frac{\theta_b}{2} - \alpha\right) \bar{j} \tag{A3}$$

The vector $\overline{OT}$ may now be written in the following form:

$$\overline{OT} = R_b \, \bar{n}_{ou} + R_b \alpha \bar{n}_{ut} \tag{A4}$$

Substitution of equations (A2) and (A3) into the above and subsequent separation into x and y-components, gives the following coordinates of an arbitrary point T on the left involute profile:

$$x_{inv} = R_b \left[-\sin\left(\frac{\theta_b}{2} - \alpha\right) - \alpha \cos\left(\frac{\theta_b}{2} - \alpha\right)\right] \tag{A5}$$

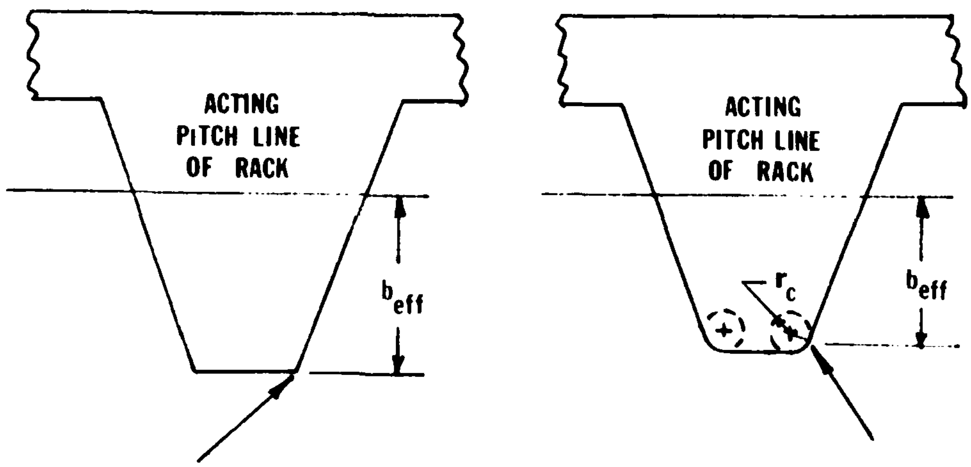
and

$$y_{inv} = R_b \left[\cos\left(\frac{\theta_b}{2} - \alpha\right) - \alpha \sin\left(\frac{\theta_b}{2} - \alpha\right)\right] \tag{A6}$$

APPENDIX B

DETERMINATION OF COORDINATES OF PATH OF EFFECTIVE RACK POINT

In order to be able to plot the root of a gear tooth, as cut by a rack cutter, it is first necessary to obtain the x and y coordinates of the trochoidal path described by the effective point of the rack cutter tooth.
Figure B-1 shows the effective points of rack cutter teeth with and without fillet radii as well as the associated effective



a. EFFECTIVE POINT FOR SHARP CORNERED RACK

b. EFFECTIVE POINT OF RACK WITH FILLET RADIUS r_c

Figure B-1

Effective Point and Effective Distance b_{eff} of Racks with and without Fillet Radii distances b_{eff}. When there is no fillet radius,(see Fig. B-1a) the corner becomes the effective rack point and b_{eff} is represented by the distance from the acting pitch line of the rack to this corner. If the rack has a fillet, the point of tangency of the rack flank and the fillet circle becomes the effective point and b_{eff} is measured to this point.

The magnitude of b_{eff} decides for a given gear or pinion whether the teeth are undercut. Figure B-2 illustrates the applicable criterion.

If the effective point of the rack cutter tooth moves horizontally along a line which passes through point U(the origin of the involute) or above it, the involute tooth will not be undercut. Thus the limiting distance b_{effmax} is given by

$$b_{effmax} = R_p - R_b \cos\theta$$

$$b_{effmax} = R_p(1 - \cos^2\theta) = R_p \sin^2\theta \qquad \text{(B1)}$$

Thus, generally,

If $b_{eff} \leq R_p \sin^2\theta$, the gear tooth <u>will not be</u> undercut. The effective point of the rack initially contacts the gear tooth-to-be-cut above its base circle.

If $b_{eff} > R_p \sin^2\theta$, the gear tooth <u>will be</u> undercut. The effective point of the rack initially contacts the tooth-

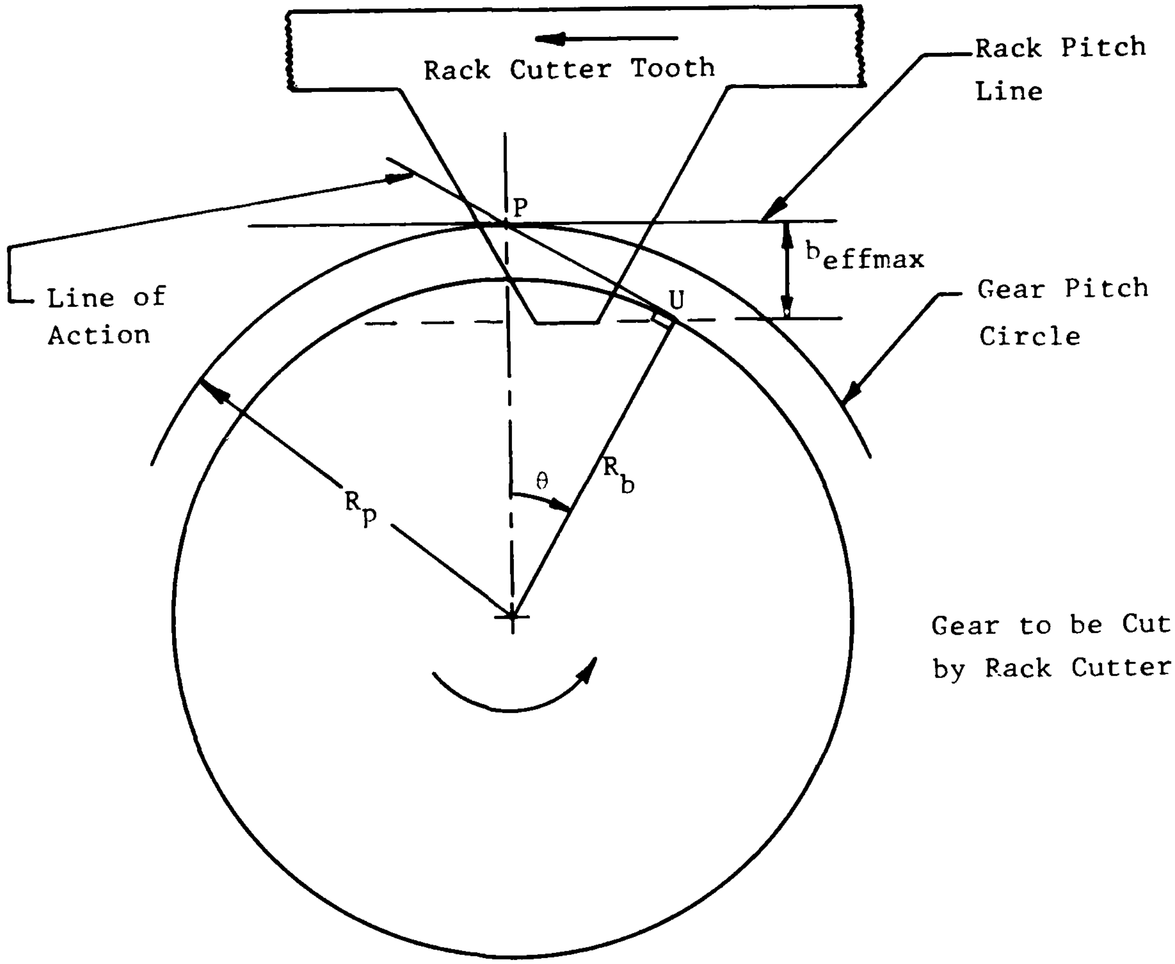


Figure B-2
Maximum Allowable b_{eff} which avoids Undercutting

to-be-cut below its base circle.

The following first gives derivations for the trochoid coordinates of the path of the effective rack point for both of the above cases. Appendix C shows how to obtain the associated coordinates of the path of the center of the fillet circle.

1. COORDINATES OF PATH OF EFFECTIVE RACKPOINT FOR $b_{eff} > R_p \sin^2\theta$

Figure B-3 shows a rack cutter, which is about to cut the root of the indicated tooth, in its standard position. The flank of the rack tooth is tangent to the initial involute point V.

The angle ψ, which defines the rolling of the rack pitch line on the gear pitch circle, is zero when line $\overline{OP}$ is at the rack pressure angle θ to the initial involute tangent $\overline{OV}$.

As the angle ψ increases in a CCW direction, a part of the undercut root of the gear tooth is generated. A clockwise decrease in the angle ψ causes the completion of this root. In actual gear hobbing, it would also cause the generation of the involute portion of the tooth. The determination of the required maximum positive and negative values of the angle ψ, which are necessary to form a sufficient portion of the root profile, together with the determination of the inner form radius of undercut teeth, is shown in APPENDIX C.

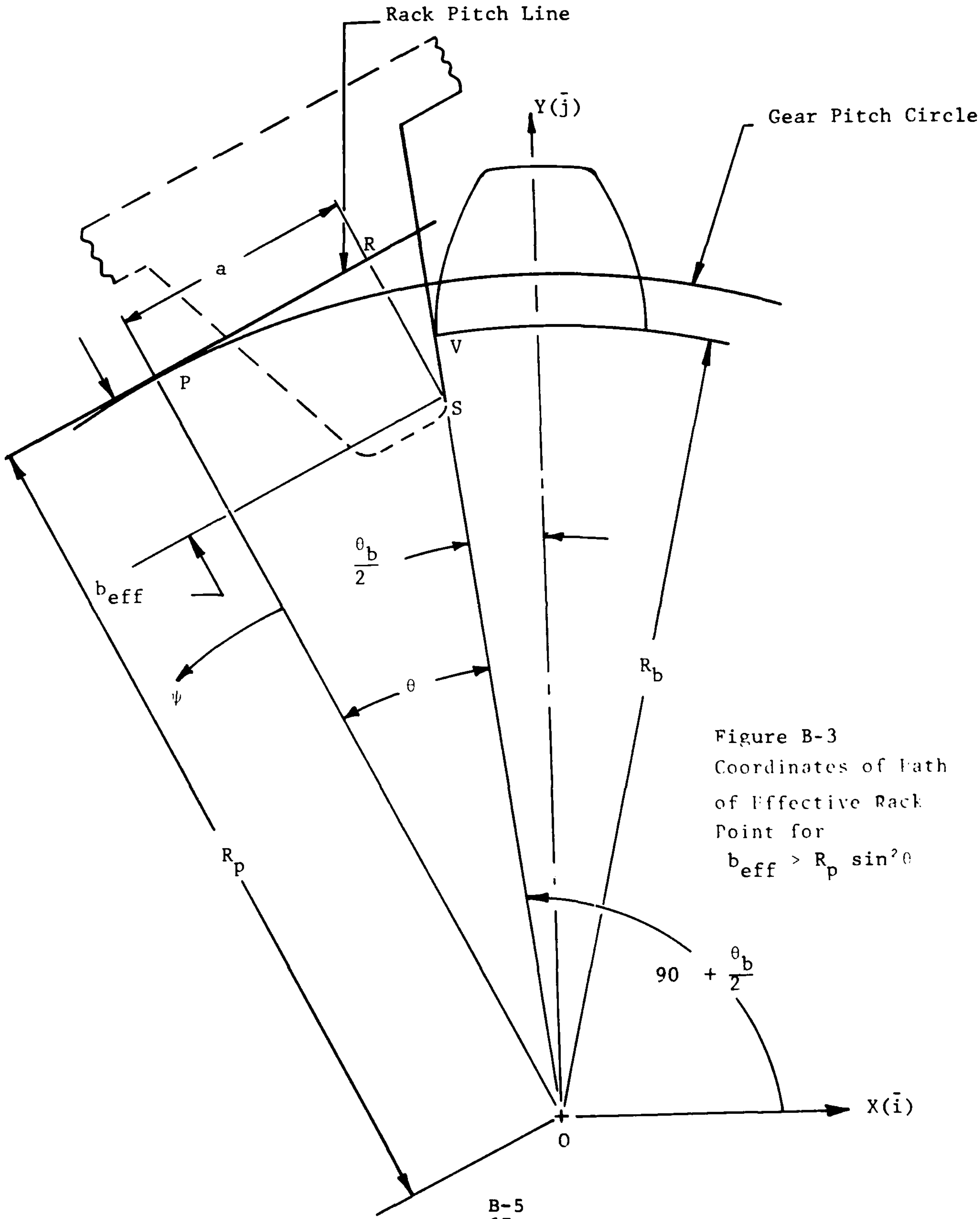


Figure B-3
Coordinates of Path of Effective Rack Point for $b_{eff} > R_p \sin^2\theta$

When $b_{eff} > R_p \sin^2\theta$, the distance from the instant center P to point R, becomes for the indicated standard position, i.e. for $\psi = 0$

$$a = (R_p - b_{eff}) \tan\theta \tag{B2}$$

For non-zero values of ψ, the distance $\overline{PR}$ is given by

$$PR = a + R_p\psi \tag{B3}$$

To define the position vector $\overline{OS}$, from the center of the gear to the effective rack point S, it is necessary to define unit vectors for the directions of lines OP and $\overline{PR}$, respectively.

$$\bar{n}_{op} = \cos(90 + \frac{\theta_b}{2} + \theta + \psi)\bar{i} + \sin(90 + \frac{\theta_b}{2} + \theta + \psi)\bar{j} \tag{B4}$$

or

$$\bar{n}_{op} = -\sin(\frac{\theta_b}{2} + \theta + \psi)\bar{i} + \cos(\frac{\theta_b}{2} + \theta + \psi)\bar{j} \tag{B5}$$

Further,

$$\bar{n}_{pr} = -\bar{k} \times \bar{n}_{op} = \cos(\frac{\theta_b}{2} + \theta + \psi)\ \bar{i} + \sin(\frac{\theta_b}{2} + \theta + \psi)\ \bar{j} \tag{B6}$$

The position vector $\overline{OS}$ may now be defined as:

$$\overline{OS} = R_p\ \bar{n}_{op} + (a + R_p\psi)\bar{n}_{pr} - b_{eff}\ \bar{n}_{op} \tag{B7}$$

Substitution of equ's (B5) and (B6) and separation of x and y components gives the following coordinates for the path of the effective rack point:

$$x_{tr} = -(R_p - b_{eff}) \sin(\frac{\theta_b}{2} + \theta + \psi)$$

$$+ (R_p\psi + a) \cos(\frac{\theta_b}{2} + \theta + \psi) \qquad \text{(B8)}$$

and

$$y_{tr} = (R_p - b_{eff}) \cos(\frac{\theta_b}{2} + \theta + \psi)$$

$$+ (R_p\psi + a) \sin(\frac{\theta_b}{2} + \theta + \psi) \qquad \text{(B9)}$$

2. COORDINATES OF PATH OF EFFECTIVE RACK POINT FOR $b_{eff} \leq R_p \sin^2\theta$

Figure B-4 shows the effective point of the rack making initial contact with point Q on the (future) involute profile. (This is considered standard position for the non-undercut teeth.) This point must be located on the line of action $\overline{UP}$. Note that, point V again represents the initial point of the involute. The angle ψ, which again defines the rolling of the rack pitch line on the pitch circle of the gear is zero in the indicated standard position, when line $\overline{OP}$ makes the rack pressure angle θ with the instantaneous base radius $\overline{OU}$ of length R_b. A clockwise decrease in ψ starts the generation of both the involute and root profiles. For a discussion of the limits of angle ψ see APPENDIX C. (Let the rack in Figure B-4 be considered to be in standard position.) For the present case, with $b_{eff} \leq R_p \sin^2\theta$, the distance a becomes:

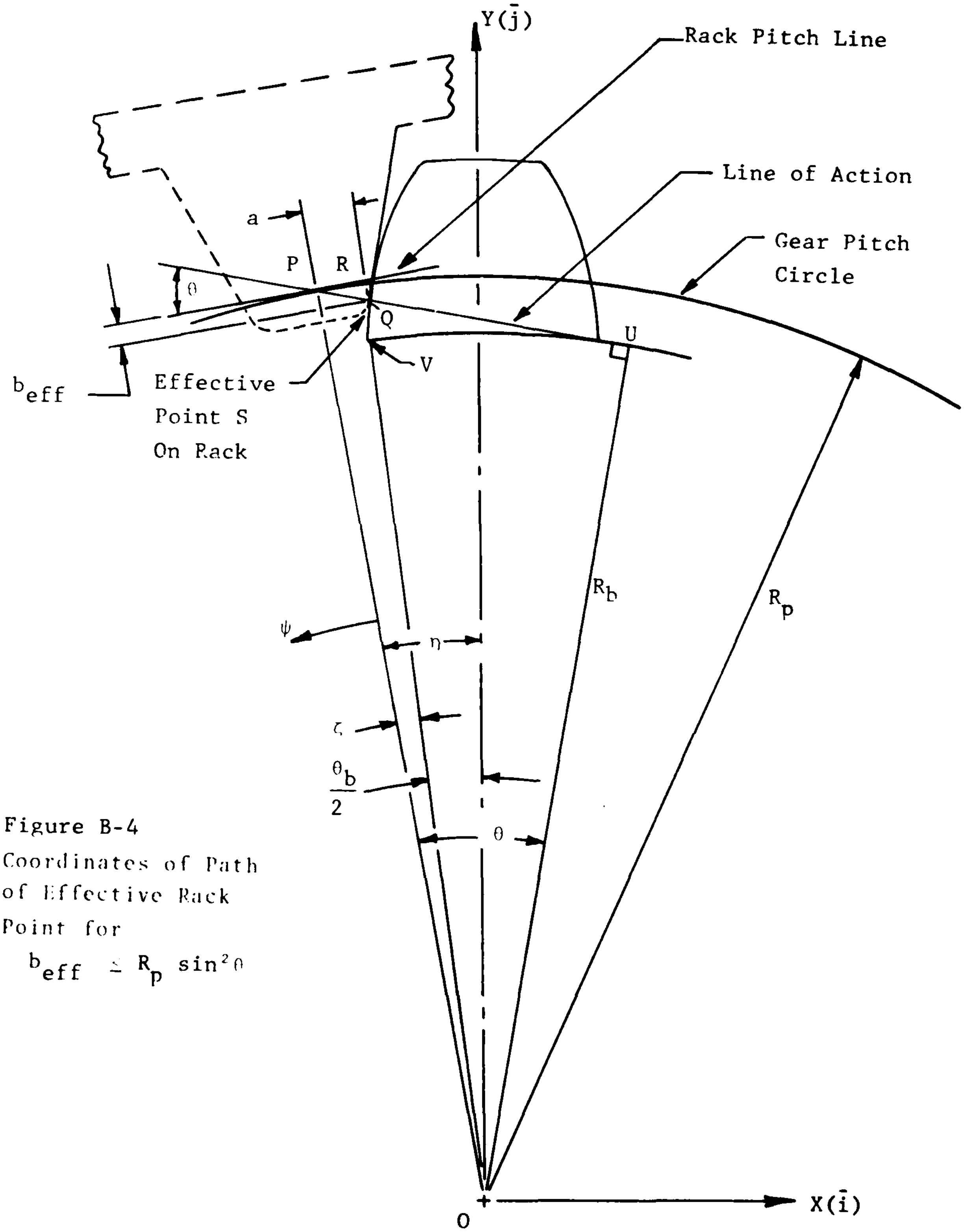


Figure B-4
Coordinates of Path
of Effective Rack
Point for
$b_{eff} \leq R_p \sin^2\theta$

$$a = \frac{b_{eff}}{\tan\ \theta} \tag{B10}$$

This represents the distance $\overline{PR}$ when $\psi = 0$. In general

$$\overline{PR} = a + R_p\psi \tag{B11}$$

To define the position vector $\overline{OS}$, from the gear center O to the effective rack point S, it is necessary to introduce unit vectors for the directions of lines $\overline{OP}$ and $\overline{PR}$, respectively, Now, (see Figure B-4):

$$\bar{n}_{op} = \cos(\ 90 + \eta + \psi\ )\bar{i} + \sin(\ 90 + \eta + \psi\ )\bar{j} \tag{B12}$$

or

$$\bar{n}_{op} = -\sin(\ \eta + \psi\ )\bar{i} + \cos(\ \eta + \psi\ )\bar{j} \tag{B13}$$

further,

$$\bar{n}_{pr} = -\bar{k} \times \bar{n}_{op} = \cos(\ \eta + \psi\ )\bar{i} + \sin(\ \eta + \psi\ )\bar{j} \tag{B14}$$

The angle η is defined as follows:

$$\eta = \frac{\theta_b}{2} + \zeta \tag{B15}$$

where

$$\zeta = \theta - \}\ \mathrm{VOU}\ , \tag{B16}$$

and θ is the pressure angle of the rack .

Further,

$$\measuredangle\, VOU = \frac{\overset{\frown}{VU}}{R_b} = \frac{\overline{QU}}{R_b} \tag{B17}$$

by the properties of the involute curve.

But

$$\overline{QU} = \overline{UP} - \overline{PR}\ , \tag{B18}$$

where

$$\overline{UP} = R_b \tan\theta \tag{B19}$$

and

$$\overline{PR} = \frac{b_{eff}}{\sin\theta}\ . \tag{B20}$$

Finally,

$$\measuredangle\, VOU = \tan\theta - \frac{b_{eff}}{R_b \sin\theta} \tag{B21}$$

and, according to equ's (B15) and (B16):

$$\eta = \frac{\theta_b}{2} + \theta + \frac{b_{eff}}{R_b \sin\theta} - \tan\theta \tag{B22}$$

The position vector $\overline{OS}$ may now be written:

$$\overline{OS} = R_p\, \bar{n}_{op} + (\, a + R_p\psi\,)\bar{n}_{pr} - b_{eff}\bar{n}_{op} \tag{B23}$$

Substitution of equ's (B13) and (B14) into the above, followed by the separation of x and y components leads to the following coordinates of the effective point for the present case

$$x_{tr} = -(R_p - b_{eff})\sin(\eta + \psi) + (R_p\psi + a)\cos(\eta + \psi) \qquad \text{(B24)}$$

and

$$y_{tr} = (R_p - b_{eff})\cos(\eta + \psi) + (R_p\,\psi + a)\sin(\eta + \psi) \qquad \text{(B25)}$$

APPENDIX C

GENERATION OF TOOTH ROOT IN PRESENCE OF FILLET RADIUS ON RACK CUTTER

The present appendix shows two methods of obtaining the coordinates of a tooth root, i.e. the portion of the tooth below the involute profile, when the rack cutter has a fillet radius r_c. Now, the root profile is not generated by the effective point, as is the case for a sharp cornered rack, but it becomes the envelope of the various positions of the fillet circle. This fillet circle serves as a generating curve.

The first method simulates the applicable drafting method of finding an envelope by a purely numerical computer procedure. The center of the fillet circle is first found for a given position of the rack pitch line. Then, the x-coordinates of points on the appropriate portion of the associated circle are found as functions of equally spaced y-coordinates. This process is repeated for other positions of the rack pitch line. For all angles ψ the x-coordinates of circle points, which are associated with certain y-coordinates , are stored in the same row of a matrix. If the angular increment of pitch line rotation is sufficiently small, that x-coordinate which is closest to the tooth center line represents the desired point on the root profile.

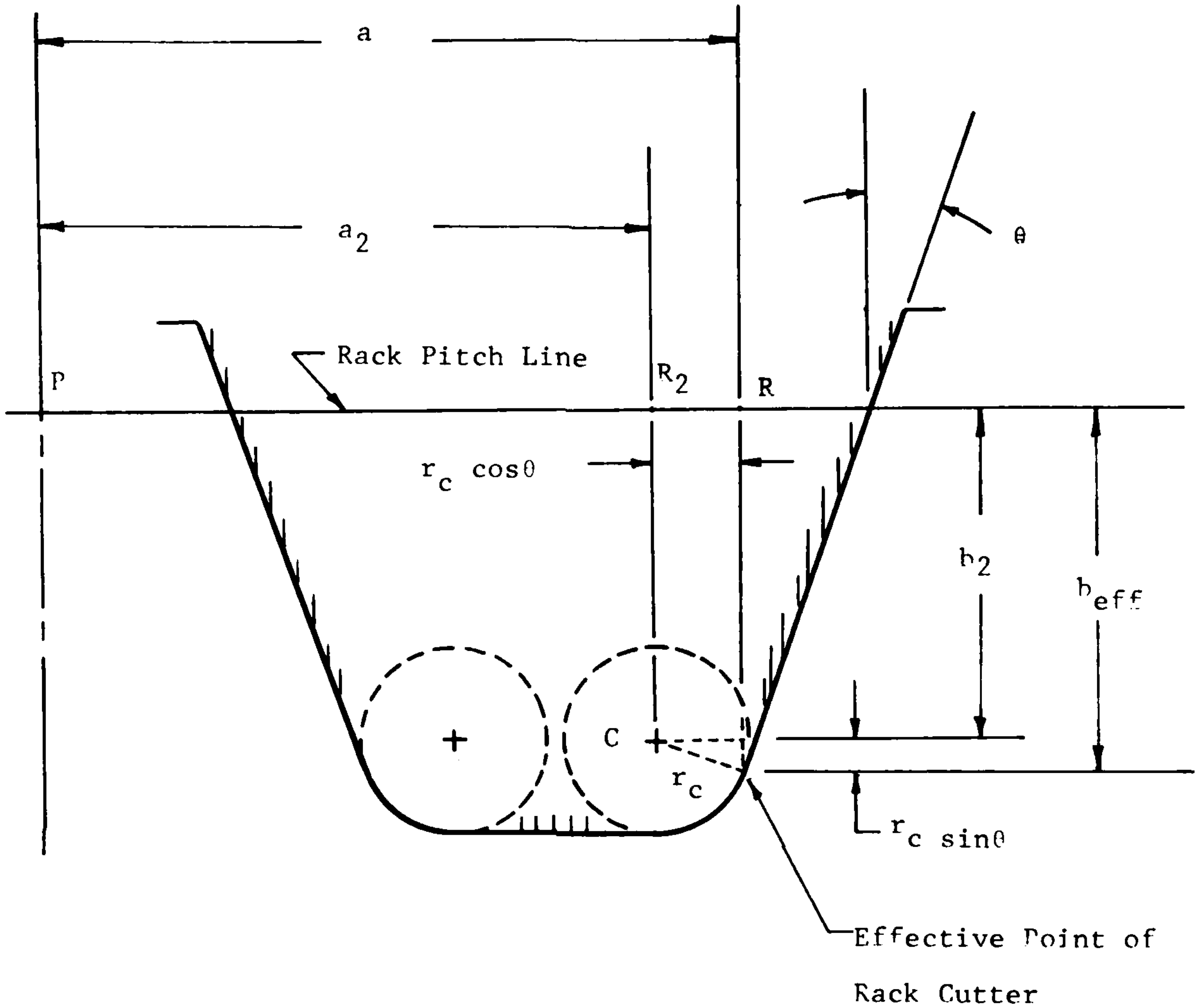


Figure C-1

Center of Fillet Radius in

Standard Position

The second method was first shown by R. G. Mitchiner and H.H. Mabie in "The Determination of the Lewis Form Factor and the AGMA Geometry Factor J for External Spur Gear Teeth". Paper No. 80-DET-59, Design Engineering Technical Conference, Beverly Hills, CA., Sept. 28 - Oct. 1, 1980. It makes use of the fact that, the instantaneous centers of curvature of a generating curve and its envelope lie on a line through the instant center of rotation of the two planes involved. The contact point between the generating curve and the envelope also lies on this line and it represents a point on the final envelope profile.

Before either of these procedures can be shown in detail, it is necessary to find a method for determining the coordinates of the center of the fillet radius as a function of the angle ψ. This is accomplished by the appropriate adaptations of the expressions given in Appendix B.

1. Coordinates of Center Of Fillet Radius for Undercut and Non-Undercut Teeth

Figure C-1 shows a rack cutter tooth as it appears both for undercut and non-undercut gear teeth in the standard position of Figure B-3 and B-4, respectively. The distance from point R, on the rack pitch line, to the effective rack point is represented by b_{eff}. The distance $\overline{PR}$, from the instant center P to point R, which corresponds to the effective rack point, is given by length a. [As before, either equ's. (B2) or (B10) are applicable.] If one wishes to express the position of the center C of the right hand fillet (of radius r_c) with respect to the instant center P in this standard position, one obtains:

$$a_2 = \overline{PR_2} = a - r_c \cos\theta \tag{C1}$$

and

$$b_2 = \overline{R_2C} = b_{eff} - r_c \sin\theta \tag{C2}$$

With the above it is now possible to adapt the coordinate expressions for the effective rack point to new ones for the fillet center C by replacing the distances a and b_{eff} by a_2 and b_2, respectively. Thus, one obtains for <u>undercut</u> teeth, according to equations (B8) and (B9):

$$x_c = -(R_p - b_2) \sin\left(\frac{\theta_b}{2} + \theta + \psi\right) + (R_p\psi + a_2) \cos\left(\frac{\theta_b}{2} + \theta + \psi\right) \tag{C3}$$

and

$$y_c = (R_p - b_2) \cos \left(\frac{\theta_b}{2} + \theta + \psi \right) + (R_p\psi + a_2) \sin \left(\frac{\theta_b}{2} + \theta + \psi \right) \tag{C4}$$

Similarly, the coordinates of the fillet center C for <u>non-undercut</u> teeth become with the help of equ's. (B24) and (B25):

$$x_c = -(R_p - b_2) \sin (\eta + \psi) + (R_p\psi + a_2) \cos (\eta + \psi) \tag{C5}$$

and

$$y_c = (R_p - b_2) \cos (\eta + \psi) + (R_p\psi + a_2) \sin (\eta + \psi) \tag{C6}$$

2. Iterative Method of Obtaining Root Profile

Figure C-2 indicates how successive fillet circles may be used to obtain the root profile envelope for undercut as well as non-undercut teeth. Point C_1 represents the fillet center when the rack cutter is in the usual standard position. The operative pitch radius is $\overline{OP} = R_{p1}$ and the coordinates of point C_1, with respect to point P, are given by a_2 and b_2 (as defined in the previous section). Centers C_2, C_3 and C_4 result after successive clockwise rotations of the rack pitch line, with associated pitch radii R_{p2}, R_{p3} and R_{p4}, respectively.

Figure C-3 represents an enlarged view of the relevant segments of two such fillet radii. It will serve to illustrate the following explanation of the computational procedure which is used to simulate the drafting method of obtaining the root envelope:

a. The coordinates x_c and y_c of centerpoint C_1 of the first circle are computed with the help of either equations (C3) and (C4) or equations (C5) and (C6), depending on whether the tooth is undercut or not.
The counter J is used to indicate the number of the circle. J = 1 for the present case

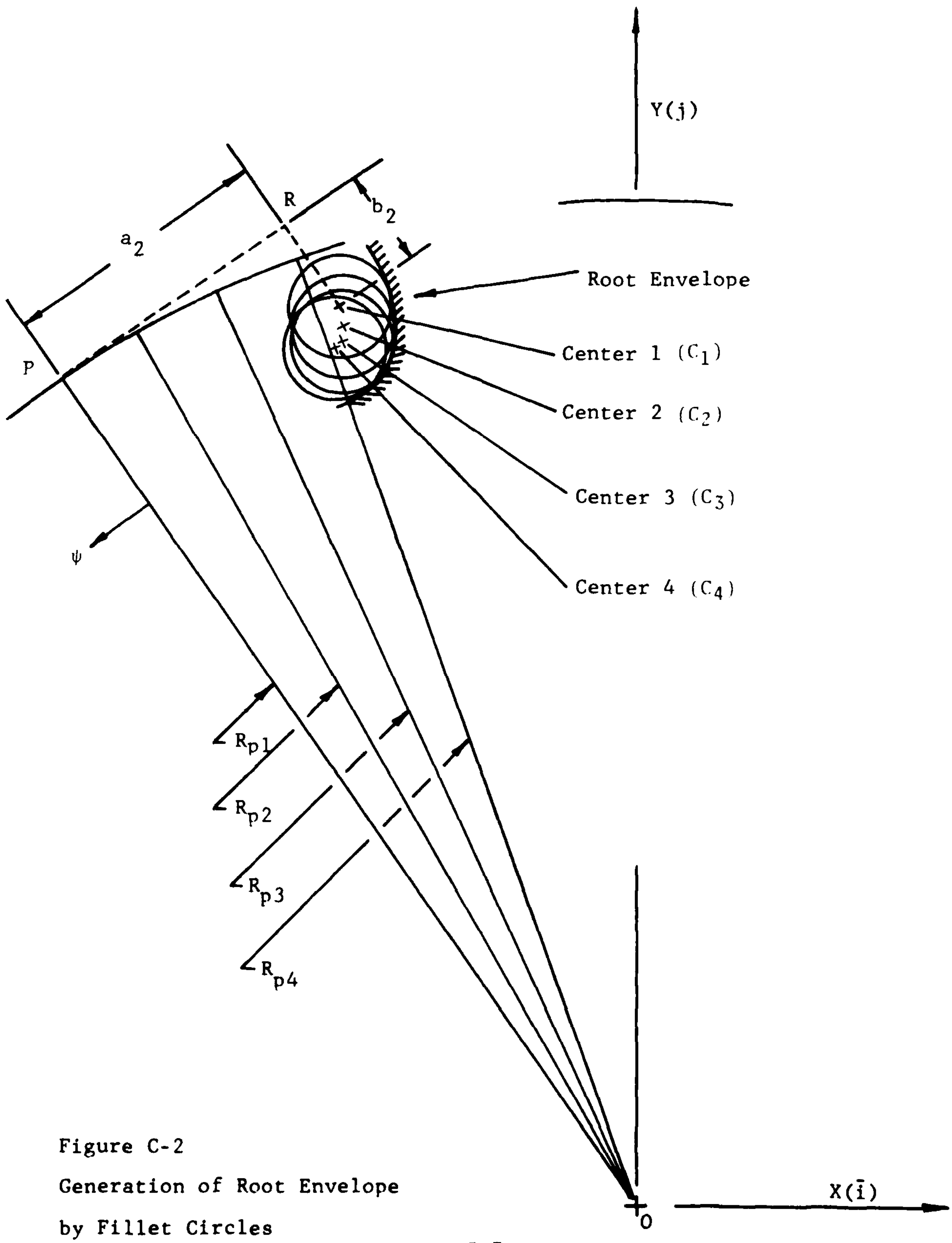


Figure C-2
Generation of Root Envelope
by Fillet Circles

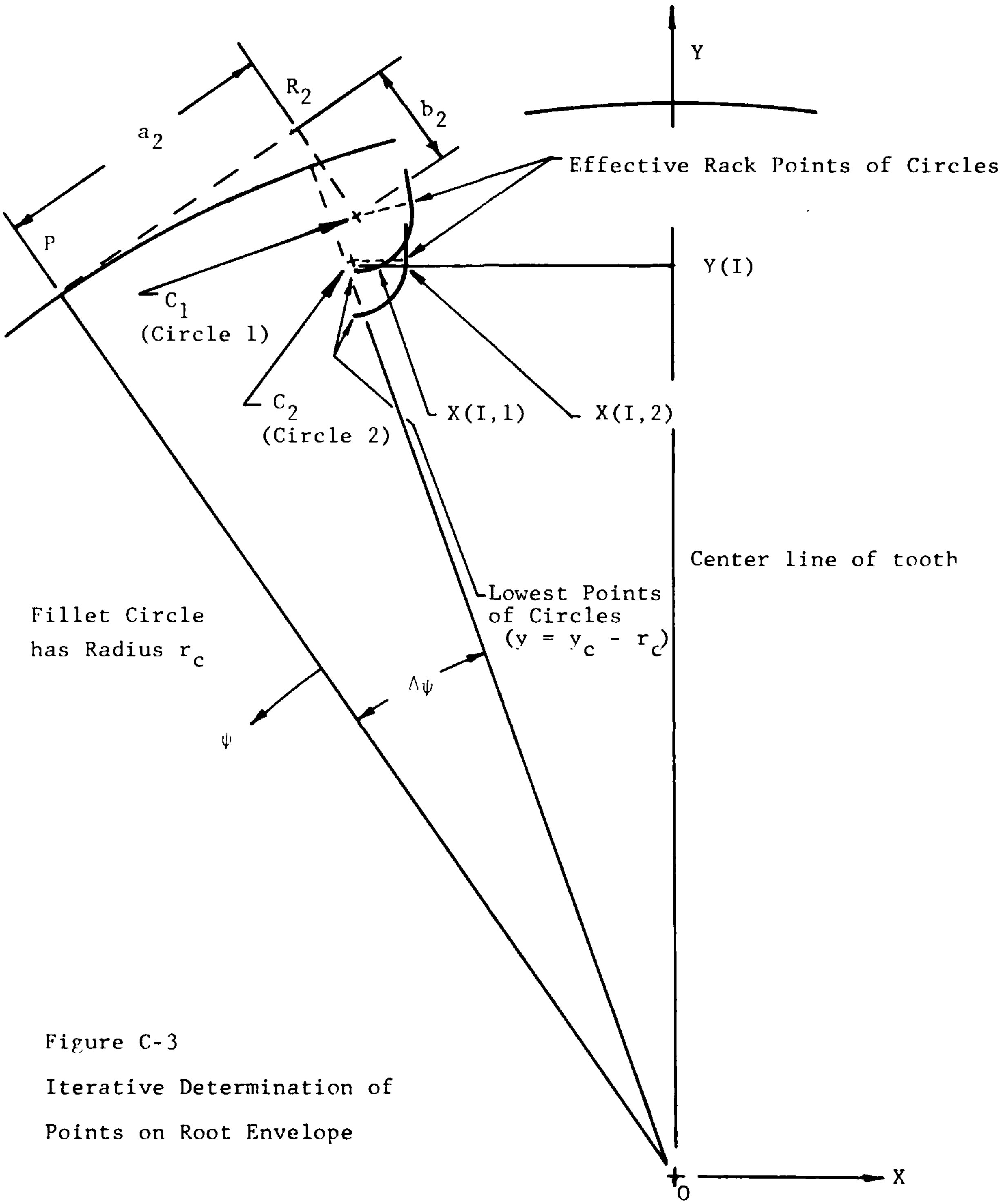


Figure C-3

Iterative Determination of

Points on Root Envelope

and generally, for that circle which corresponds to the intial angle ψ_{in}. The total number of circles depends on the increment $\Delta\psi$ as well as on the final angle ψ_{fin}. (These initial and final angles are defined in Appendix D).

b. Since the center of the fillet circle never lies at the origin, the equation for points on the circle is given by:

$$(x - x_c)^2 + (y - y_c)^2 = r_c^2 \quad \text{(C7)}$$

The x-coordinates of points on this circle, for a given value of the y-coordinate, may be obtained from

$$x = x_c \pm \sqrt{r_c^2 - (y - y_c)^2} \quad \text{(C8)}$$

For practical purposes it is only necessary to obtain the x-coordinates of points whose y-coordinates are located between the effective rack point of a given circle and $y = y_c - r_c$ (See Figure C-3).(*) Since the center of all

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(*)Points above the effective point on the rack flank are not involved in the generation of the final root profile.

generating circles lie in the second quadrant, their x-coordinates will always be negative.

Further, since the circle segments of interest will always be located to the right of their center points, the values of all x-coordinates will be larger than those of their associated x_c's. For this reason, the positive sign must be used in equation (C8), i.e.:

$$x = x_c + \sqrt{r_c^2 - (y - y_c)^2} \qquad \text{(C9)}$$

c. The computation is continued by determining the y-coordinate of the effective rack point of circle 1 either with the help of equ. (B9) or equ. (B25), depending on whether the tooth is undercut or not.

The y-coordinates are assigned the counter I and they will be stored in the vector Y(I). For this specific computation I = 1. The associated x-coordinate is then found with the help of equ. (C9), and its values is stored in the matrix X(I,J). Since this is the first x-coordinate of circle 1, it will be located by X(1,1). Subsequently, the first y-coordinate is decremented by .001 inch and its associated x-coordinate is again obtained with the help of equ. (C9). The value of the y-coordinate is stored in Y(2), while the x-coordinate belongs to X(2,1). This process is repeated until $y = y_c - r_c$ (with the y_c of circle 1), filling the appropriate Y(I) and X(I,1).

d. The angle ψ is now decremented by $\Delta\psi$, as indicated by Figure C-3. J = 2 for this second position of the fillet circle. Again, the coordinates x_c and y_c of point C_2 are found, together with the y-coordinate of the effective rack point of circle 2. The later is identical to one of the y-coordinates of circle 1. In order to find the value of I which corresponds to this Y(I) of circle 1, all previously computed values of Y(I) are compared to the present one. (This sorting process is made possible by multiplying the values of all the y-coordinates stored in Y(I) by one thousand and then truncating them to make a four digit integer out of them. (See Program description in Section 2). Once the specific value of I = f has been found, it is assigned to X(f,2) for storing the x-coordinate of the effective point of circle 2. The process of decrementing the y-coordinates of the second circle by .001 inch each time and computing the associated x-coordinates, until the lower limit of this circle has been reached, follows. It is identical to the one described for circle 1 in part (c) above. All values of these coordinates are assigned to the appropriate Y(I) and X(I,2).

(The above operations are repeated in the program many times. Table C-1, which shows a typical vector Y(I) and its associated matrix X(I,J) will be discussed below).

e. Figure C-3 shows two circle points on the horizontal line through Y(I). These are X(I,1) on circle 1 and X(I,2) on circle 2. Since X(I,2) is closest to the tooth center line, it becomes the accepted value for the x-coordinate

col.1	col.2	col.3	col.4	col.5	col.6	col.7	col.8
I	Y(I)	X(I,1) J = 1 $\psi = 0^{\circ}$	X(I,2) J = 2 $\psi = -3^{\circ}$	X(I,3) J = 3 $\psi = -6^{\circ}$	X(I,4) J = 4 $\psi = -9^{\circ}$	X(I,5) J = 5 $\psi = -12^{\circ}$	X(I,6) J = 6 $\psi = -15^{\circ}$
1	3.628	-.981					
19	3.610	-.977					
29	3.600	-.976					
49	3.580	-.974					
66	3.563	-.974	-.968				
104	3.525	-.978	-.963				
122	3.507	-.982	-.963	-.963			
169	3.460	-1.001	-.969	-.960	-.966		
206	3.423	-1.027	-.982	-.965	-.965	-.976	
231	3.398	-1.051	-.995	-.972	-.968	-.976	-.992
289	3.340		-1.045	-1.001	-.986	-.987	-.999
342	3.287			-1.053	-1.020	-1.013	-1.021
387	3.242				-1.073	-1.051	-1.054
421	3.208					-1.101	-1.094
446	3.183						-1.143
459	3.170						-1.208

Table C-1

Typical Vector Y(I) and Matrix X(I,J)

(Diagonal lines indicate largest value in any row. All values in inches).

of the tooth profile associated with Y(I). (In the actual program there are many X(I,J) values for a given Y(I). Again, that x-coordinate which is closest to the tooth center line becomes the desired point on the root profile).

Table C-1 illustrates the relationship between the vector Y(I) and the matrix X(I,J) with selected numbers from an actual computer run. Column 1 contains the counter I which identifies the y-coordinates on the fillet circle segments. While I takes values from 1 to 459, in steps of one, in the actual run, the table shows only a limited number of y-coordinates. Column 2 contains these coordinates. Each one is common to all circle points on the same horizontal line. Columns 3 to 8 list the x-coordinates of these circle points. With $\psi_{in} = 0^o$, $\psi_{fin} = -15^o$ and $\Delta\psi = -3^o$, the counter J, which identifies the circle number, ranges from 1 to 6. The first number in each column represents the x-coordinate of the effective point of the rack in the given position. (This was the basis of the choice of the I's in the table).

Once such a "table" has been completed by the computer, the x-coordinates of the root profile are determined by the largest (i.e. least negative) number in any one row of the matrix X(I,J). For example for I = 231, where y = 3.398 in., the profile coordinate x = -.968 in.

3. Analytical Method of Obtain Root Profile Coordinates

Figure C- 4 shows a rack with a fillet radius r_c which is generating the indicated root profile. Since the Euler-Savary Curvature Theory(**) shows that, the contact point between a generating curve and its envelope lies on a line connecting the instant center P and the center of curvature C of the generating curve, point S represents a point on the root profile. To obtain the coordinates of this envelope point the components of the vector

$$\overline{OS} = \overline{OC} + \overline{CS} = \overline{OC} + r_c \bar{n}_{cs} \tag{C10}$$

must be determined. The unit vector $\overline{n_{cs}}$ has the direction of line $\overline{PC}$, as indicated above.

The components of the vector $\overline{OC}$ were given by equ's. (C3) and (C4) or by equ's. (C5) and (C6) for undercut and non-undercut teeth, respectively.

In order to obtain a single set of expressions, certain angles, found in the above equations, and which were first introduced

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(**) N. Rosenauer and A. H. Willis: Kinematics of Mechanisms, pp. 60-62, Dover Publications, Inc., No. S1796, New York, 1967.

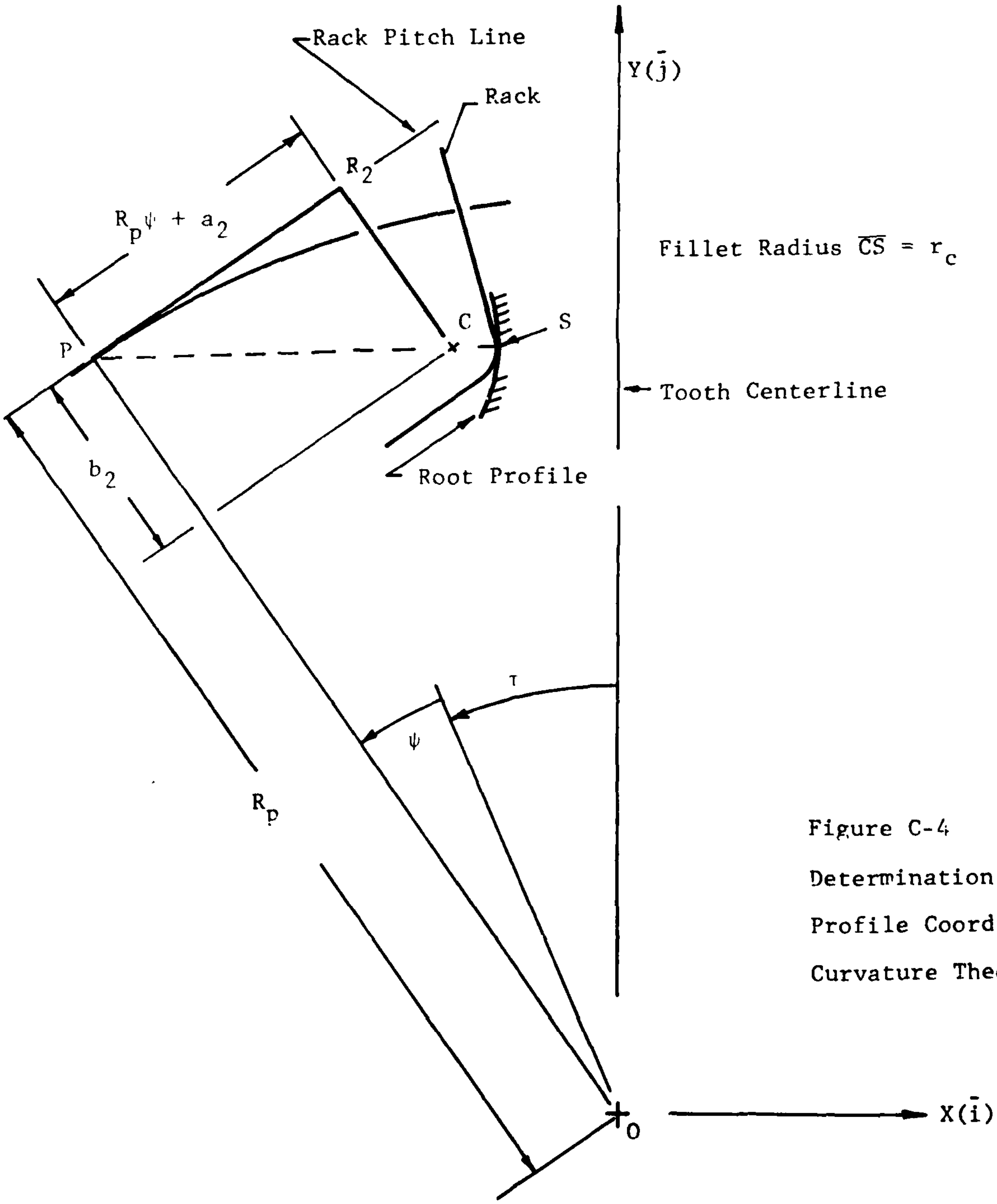

Figure C-4

Determination of Root Profile Coordinates by Curvature Theory in Appendix B, are now redefined as follows (see Figure C-4):

For undercut teeth, let

$$\tau = \frac{\theta_b}{2} + \theta \tag{C11}$$

[See also unit vectors $\bar{n}_{op}$ and $\bar{n}_{pr}$ for undercut teeth, as given by equ's. (B5) and (B6)].

For non-undercut teeth , let

$$\tau = \eta = \frac{\theta_b}{2} + \theta + \frac{b_{eff}}{R_b \sin\theta} - \tan\theta \tag{C12}$$

[Compare the above to the angles of the unit vectors of equ's. (B13) and (B14)].

With the above, equ's. (C3) to (C6) can be generalized to the following form.

For the x-component of vector $\overline{OC}$:

$$x_c = -(R_p - b_2)\sin(\tau + \psi) + (R_p\psi + a_2)\cos(\tau + \psi) \tag{C13}$$

For the y-component of vector $\overline{OC}$:

$$y_c = (R_p - b_2)\cos(\tau + \psi) + (R_p\psi + a_2)\sin(\tau + \psi) \tag{C14}$$

To derive an expression for the unit vector $\bar{n}_{cs}$, it is first necessary to express the unit vector $\bar{n}_{op}$ and $\bar{n}_{pr}$, alluded to earlier, in terms of the angle τ. Thus,

$$\bar{n}_{op} = -\sin(\tau + \psi)\bar{i} + \cos(\tau + \psi)\bar{j} \tag{C15}$$

and

$$\bar{n}_{pr} = \cos(\tau + \psi)\bar{i} + \sin(\tau + \psi)\bar{j} \tag{C16}$$

Then, as Figure C-4 shows:

$$\bar{n}_{cs} = \frac{\overline{PC}}{|\overline{PC}|} = \frac{(PR)\bar{n}_{pr} - (RC)\bar{n}_{op}}{\sqrt{(PR)^2 + (RC)^2}} \tag{C17}$$

or, with the appropriate substitution:

$$\bar{n}_{cs} =$$

$$\frac{(R_p\psi + a_2)[\cos(\tau + \psi)\bar{i} + \sin(\tau + \psi)\bar{j}] - b_2[-\sin(\tau + \psi)\bar{i} + \cos(\tau + \psi)\bar{j}]}{\sqrt{(R_p\psi + a_2)^2 + b_2^2}} \tag{C18}$$

or

$$\bar{n}_{cs} =$$

$$\frac{[(R_p\psi + a_2)\cos(\tau + \psi) + b_2\sin(\tau + \psi)]\bar{i} + [(R_p\psi + a_2)\sin(\tau + \psi) - b_2\cos(\tau+\psi)]\bar{j}}{\sqrt{(R_p\psi + a_2)^2 + b_2^2}} \tag{C19}$$

Finally, the root envelope coordinates x_{env} and y_{env} may be determined according to equ. (C10).

$$\overline{OS} = x_c \bar{i} + y_c \bar{j} + r_c \bar{n}_{cs} \tag{C20}$$

with the help of equ's. (C13), (C14) and (C19), one obtains:

$$x_{env} = -(R_p - b_2) \sin(\tau + \psi) + (R_p\psi + a_2) \cos(\tau + \psi)$$
$$+ r_c \frac{(R_p\psi + a_2) \cos(\tau + \psi) + b_2 \sin(\tau + \psi)}{\sqrt{(R_p\psi + a_2)^2 + b_2^2}} \tag{C21}$$

and

$$y_{env} = (R_p - b_2) \cos(\tau + \psi) + (R_p\psi + a_2) \sin(\tau + \psi)$$
$$+ r_c \frac{(R_p\psi + a_2) \sin(\tau + \psi) - b_2 \cos(\tau + \psi)}{\sqrt{(R_p\psi + a_2)^2 + b_2^2}} \tag{C22}$$

APPENDIX D

INITIAL AND FINAL ANGLES FOR TROCHOID AND INVOLUTE GENERATION

When computing gear tooth profile coordinates it is necessary to know the initial and final values of the trochoid generating angle ψ (see Appendix B) as well as of the involute generating angle α (called roll angle in Appendix A).

The following shows how the relationship of the trochoidal path of the effective point of the rack cutter with respect to the rest of the gear tooth profile may be utilized to determine these angles for undercut and non-undercut teeth. It must be kept in mind that, while the effective point of the cutter tooth always determines the magnitude of the inner form radius and with that the initial trochoid generating angle ψ_{in}, it does not furnish the angle associated with the lowest point of the gear root whenever there is a fillet radius on the cutter. This final trochoid angle ψ_{fin} is defined as that angle for which the effective point of the cutter coincides with the centerline of its trochoidal path (see sections 4 and 5 below).

The initial involute generating angle α_{in} is a function of the inner form radius. The final involute generating angle α_{fin} depends on the outside radius of the gear tooth.

Sections 1 and 2, on the trochoid angle τ and on the determination of the inner form radius for undercut teeth respectively, are taken with minor nomenclature changes from the work of R.A. Shaffer: An Analysis of the Undercut Problem in Involute Spur Gearing, Report No.R-1606,OMS5530.11.557, DA Project 505-01-003, Frankford Arsenal, Pitman-Dunn Laboratories, May 1962.

1. The Trochoid Angle τ

Figure D-1 shows the trochoid described by the effective point of the indicated rack tooth. The line $\overline{S'U'}$, of length b_{eff}, coincides with the center line $\overline{SU}$ of the trochoid when the generating angle ψ', as used for this purpose, is zero together with the length $\overline{QS}$, along the rack pitch line. The trochoid angle τ is measured from the trochoid center line and it defines the position of the radius R (used later to get the form radius R_f) from the orgin O to the instantaneous location of the effective rack point at U'. Then,

$$\tau = \sigma - \psi' \tag{D1}$$

where

$$\sigma = \measuredangle TOU' = \tan^{-1} \frac{\overline{TU'}}{\overline{TO}} = \tan^{-1} \frac{\sqrt{R^2 - (R_p - b_{eff})^2}}{R_p - b_{eff}} \tag{D2}$$

and

$$\psi' = \frac{\text{arc}\ \overset{\frown}{QS}}{R_p} = \frac{\overline{QS'}}{R_p} = \frac{\overline{TU'}}{R_p} = \frac{\sqrt{R^2 - (R_p - b_{eff})^2}}{R_p} \tag{D3}$$

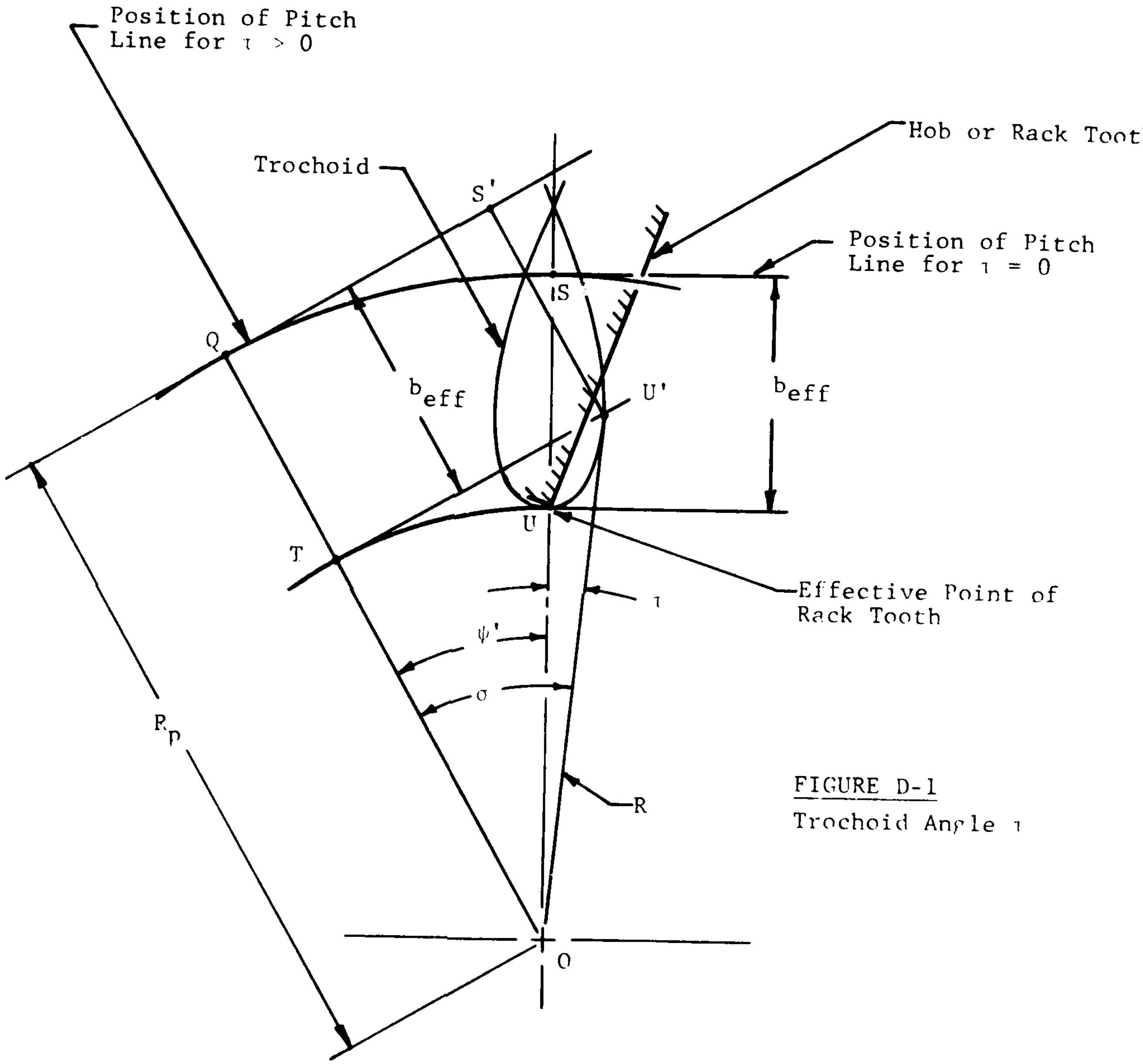

FIGURE D-1
Trochoid Angle τ

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AUTOMATED STRENGTH DETERMINATION FOR INVOLUTE FUZE GEARS.(U)
FEB 82 G G LOWEN, C KAPLAN DAAK10-79-C-0251
UNCLASSIFIED ARLCD-CR-81060 NL

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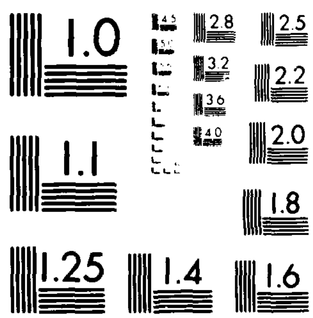

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Substitution of equ's (D2) and (D3) into equ. (D1) furnishes:

$$\tau = \tan^{-1} \frac{\sqrt{R^2 - (R_p - b_{eff})^2}}{R_p - b_{eff}} - \frac{\sqrt{R^2 - (R_p - b_{eff})^2}}{R_p} \qquad \text{(D4)}$$

2. Determination of Inner Form Radius for Undercut Teeth

Figure D-2 shows the side of a basic rack of pressure angle θ in line with the base radius $\overline{OV} = R_b$, of the indicated involute surface. Point V represents the theoretical origin of this involute. The effective point of the rack cutter, shown at point U', is positioned such that the involute profile will be undercut, i.e. $b_{eff} > R_p \sin^2\theta$. The trochoid of this effective point intersects the involute at point P and the length $\overline{OP}$ represents the inner form radius R_f. Note that the center line of the trochoid is represented by line $\overline{OU}$, which forms angle δ with the side of the rack tooth.

To obtain an expression for R_f one sets the following angles equal to each other:

$$\tau = \delta + \beta \qquad \text{(D5)}$$

where

$\tau =$ obtained from equ. (D4), with $R = R_f$

Further,

$$\delta = \theta - \psi' , \qquad \text{(D6)}$$

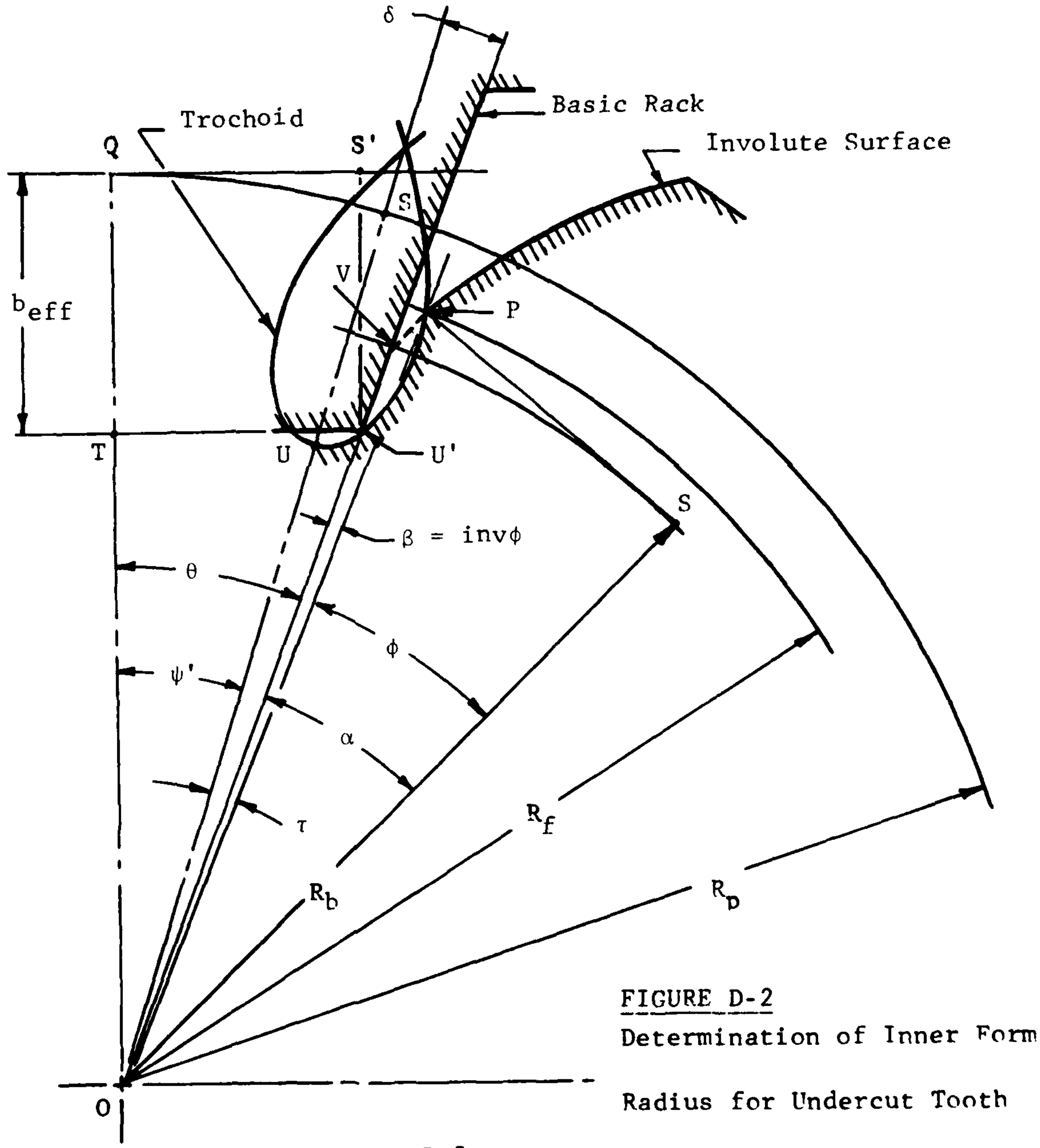


FIGURE D-2
Determination of Inner Form Radius for Undercut Tooth

where ψ' may now be expressed in terms of the rack pressure angle θ. [See also equ. (D3)].

$$\psi' = \frac{\widehat{QS}}{R_p} = \frac{QS'}{R_p} = \frac{(R_p - b_{eff})\tan\theta}{R_p} \tag{D7}$$

The angle β has its origin in involutometry. If the angle α represents the involute generating angle with respect to base radius $\overline{OV}$, and if one defines the angle POS = ϕ, then:

$$\beta = \text{INV } \phi = \tan\phi - \phi = \frac{\sqrt{R_f^2 - R_b^2}}{R_b} - \tan^{-1}\frac{\sqrt{R_f^2 - R_b^2}}{R_b} \tag{D8}$$

Substitution of equ's. (D4), (D6), (D7) and (D8) into equ. (D5) furnishes:

$$\tan^{-1}\frac{\sqrt{R_f^2 - (R_p - b_{eff})^2}}{R_p - b} - \frac{\sqrt{R_f^2 - (R_p - b_{eff})^2}}{R_p}$$

$$= \theta - \frac{(R_p - b_{eff})\tan\theta}{R_p} + \frac{\sqrt{R_f^2 - R_b^2}}{R_b} - \tan^{-1}\frac{\sqrt{R_f^2 - R_b^2}}{R_b} \tag{D9}$$

This expression may be solved for R_f either by a computer adaptation of the Newton - Raphson method or by a trial and error method.

3. Determination of Inner From Radius for Non-undercut Teeth

Figure D-3 shows the effective point of a rack cutter making initial contact with the prospective involute surface above the origin point V of the involute. Since now $b_{eff} < R_p \sin^2\theta$, the tooth will not be undercut.

As in Figure B-4 of Appendix B, the contact point Q and with that the effective point lie on the line of action $\overline{UP}$. The inner form radius R_f may be described as follows:

$$R_f = \sqrt{(\overline{QU})^2 + R_b^2} \tag{D10}$$

where

$$\overline{QU} = \overline{PU} - \overline{PQ} = R_b \tan\theta - \frac{b_{eff}}{\sin\theta} \tag{D11}$$

with the above, equ. (D10) becomes:

$$R_f = \sqrt{\left(R_b \tan\theta - \frac{b_{eff}}{\sin\theta}\right)^2 + R_b^2} \tag{D12}$$

For the special case when $b_{eff} = R_p \sin^2\theta$, equ. (D12) becomes:

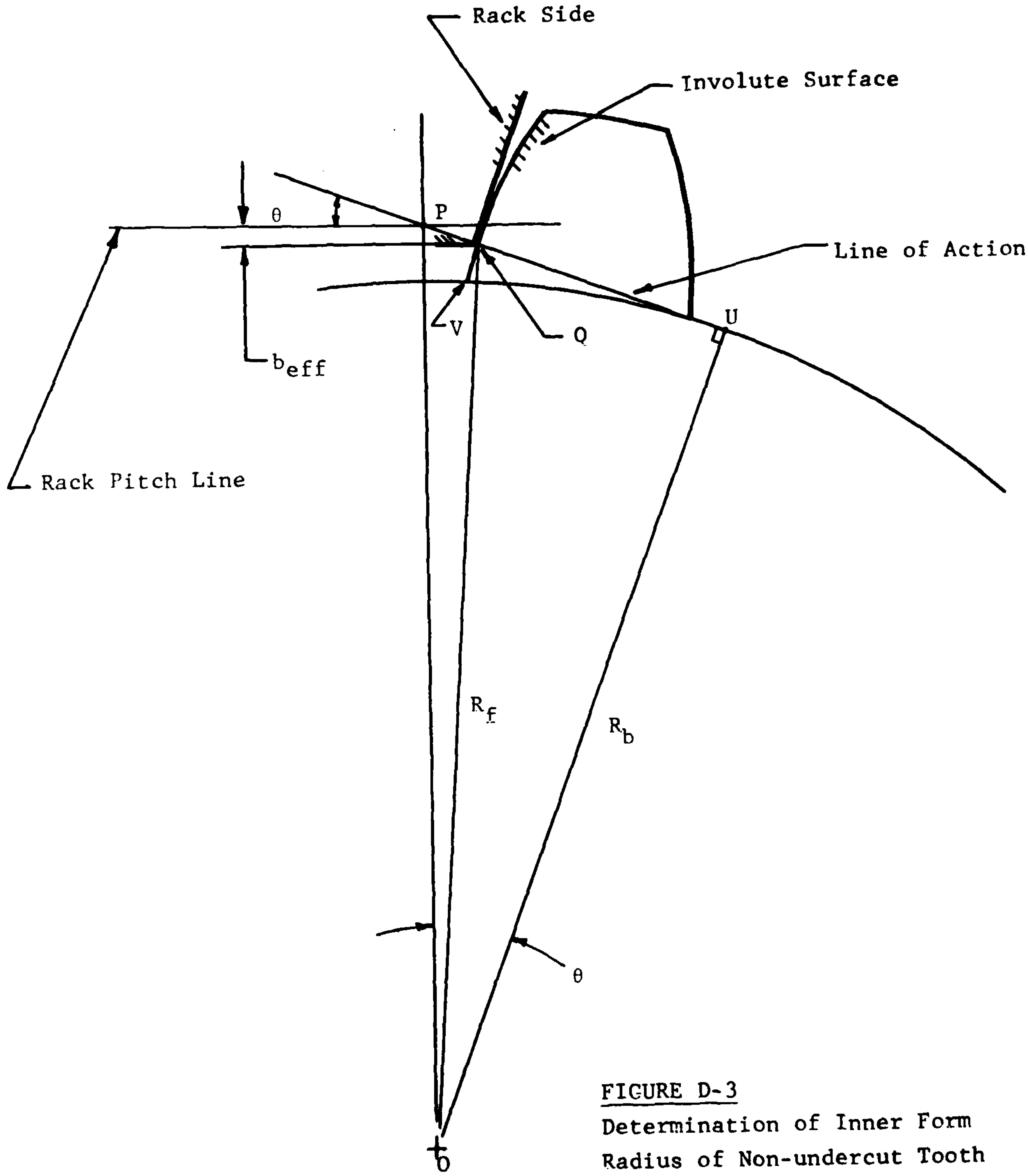


FIGURE D-3
Determination of Inner Form Radius of Non-undercut Tooth

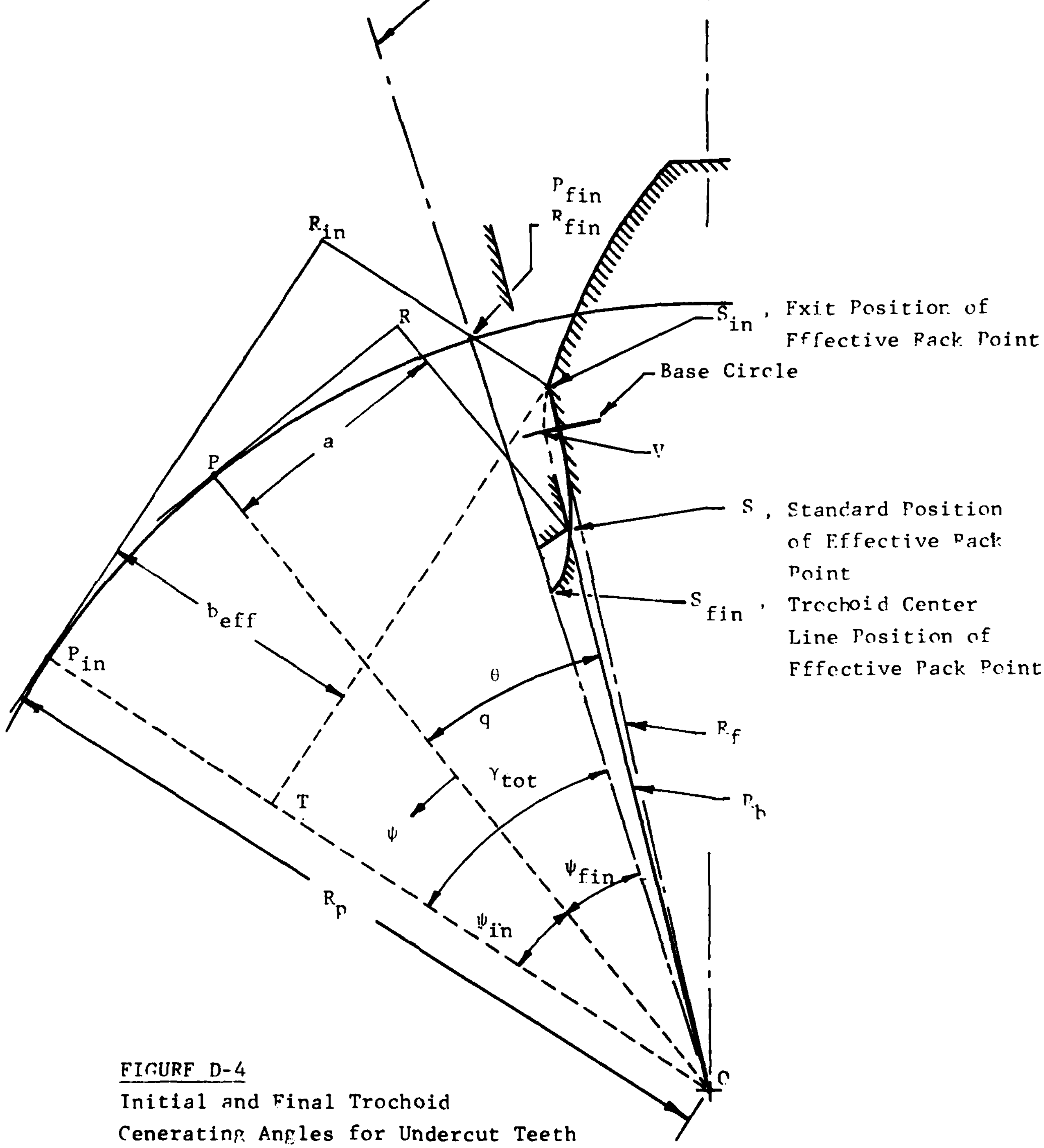


FIGURE D-4
Initial and Final Trochoid
Generating Angles for Undercut Teeth

$$R_f = R_b \,, \tag{D13}$$

as is to be expected.

4. Determination of Initial and Final Trochoid Generating Angles for Undercut Teeth

Figure D-4 shows the outline of the rack cutter in its standard position, as defined in Appendix B. The effective point of the rack makes contact with the undercut trochoid, generated by it, at point S. The flank of the rack is in line with base radius $\overline{OV} = R_b$, where V represents the origin of the involute curve. The associated line $\overline{OP} = R_p$ to the pitch point is at the pressure angle θ of the cutter with respect to line $\overline{OV}$. The angle ψ is zero. Also, the distance $\overline{PR}$, along the pitch line and normal to b_{eff}, equals a, as given by equ. (B2) in Appendix B.

In order for the effective point to make contact with point S_{fin} at the trochoid center line, the rack pitch line must roll clockwise through the angle ψ_{fin} until points P_{fin} and R_{fin} coincide. The distance rolled through equals $a = \overline{PR}$, and therefore:

$$\psi_{fin} = - \frac{a}{R_p} \tag{D14}$$

(Note that the above angle is negative because of the zero position of ψ.)

When the effective point of the rack cutter is located at point S_{in}, the intersection of the trochoid and the involute surface, $\psi = \psi_{in}$. To determine this angle, one must first find the total roll angle γ_{tot} of the pitch line, associated with the change of the effective point from S_{in} to S_{fin} . γ_{tot} depends on the arc length $\widehat{P_{in}P_{fin}} = \overline{P_{in}R_{in}}$ and it equals the angle between the pitch radii $\overline{OP}_{in}$ and $\overline{OP}_{fin}$. With the inner form radius R_f known, one obtains

$$\widehat{P_{in}P_{fin}} = \overline{T\,S}_{in} = \sqrt{R_f^2 - (R_p - b_{eff})^2} \tag{D15}$$

R_f must be computed with the help of equ. (D9).

Then:

$$\gamma_{tot} = \frac{\text{arc } \widehat{P_{in}P_{fin}}}{R_p} = \frac{\sqrt{R_f^2 - (R_p - b_{eff})^2}}{R_p} \tag{D16}$$

Finally, as figure D-4 indicates:

$$\psi_{in} = \gamma_{tot} - \left|\psi_{fin}\right| \tag{D17}$$

or

$$\psi_{in} = \frac{\sqrt{R_f^2 - (R_p - b_{eff})^2}}{R_p} - \frac{a}{R_p} \qquad \text{(D18)}$$

5. Initial and Final Trochoid Generating Angles for Non-Undercut Teeth

Figure D-5 shows the effective point of the rack cutter making initial contact with the involute profile at point S. Since this point lies on the line of action $\overline{UP}$, located above the origin V of the involute, there will be no undercutting. (Note that this figure describes the same relationship between rack and involute as Figure B-4 of Appendix B). The distance $\overline{PR}$ along the rack pitch line equals a, as defined by equ. (B10). The generating angle ψ equals zero in this initial position, while the angle between the pitch radius $\overline{OP} = R_p$ (with point O not shown) and the base radius $\overline{OU} = R_b$ equals θ, the pressure angle of the rack.

In order for the effective point of the cutter to make contact with point S_{fin} at the trochoid center line, the rack pitch line must, as in the last section, roll clockwise through the angle ψ_{fin} until points P_{fin} and R_{fin} concide. The distance rolled through is again given by $\overline{PR} = a$. (It is important to remember that the length a is now given by equ. (B10), rather than by equ. (B2) of Appendix B). Therefore,

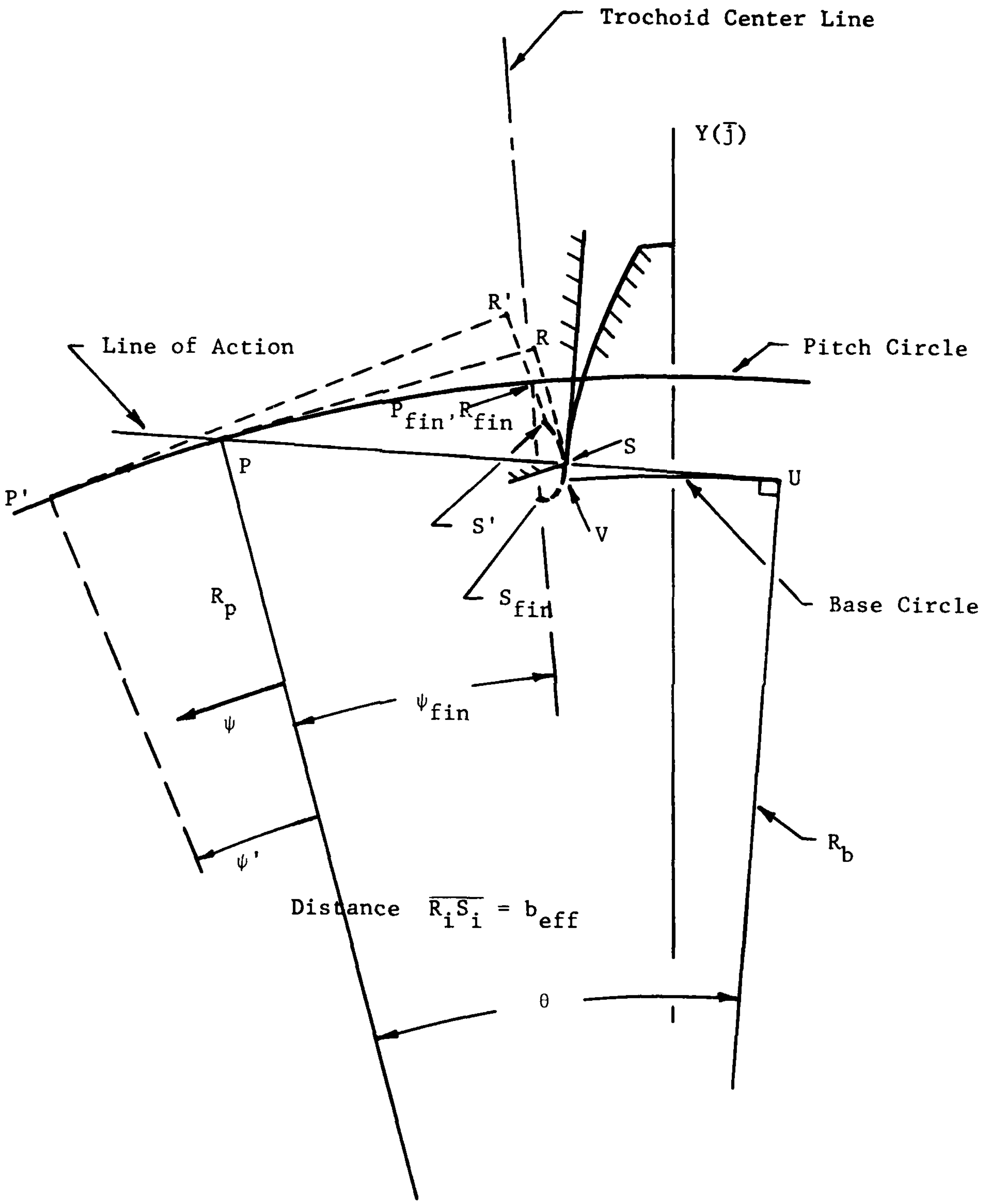


Figure D-5
INITIAL AND FINAL TROCHOID
GENERATING ANGLES FOR NON-UNDERCUT TEETH

$$\psi_{fin} = - \frac{a}{R_p} \tag{D19}$$

It can be shown that, between points S and S_{fin} the trochoid profile moves away from the theoretical involute prufile $\overline{SV}$. In addition, point S also respresents the last point of tangency between the trochoid and the involute, as angle ψ increases. To make this clear, figure D-5 shows that point S', which is associated with the arbitrary positive angle ψ', is at a considerable distance from the involute profile. For the above reason

$$\psi_{in} = 0 \tag{D20}$$

6. Initial and Final Involute Generating Angles for Undercut and Non-Undercut Teeth

Figure D-6 indicates that, once the inner form radius is known, the initial involute generating angle α_{in} may be computed, regardless of whether the tooth is undercut or not, with the help of the following:

$$\alpha_{in} = \frac{\overset{\frown}{V\,U_{in}}}{R_b} = \frac{\overline{T_{in}U_{in}}}{R_b} \tag{D21}$$

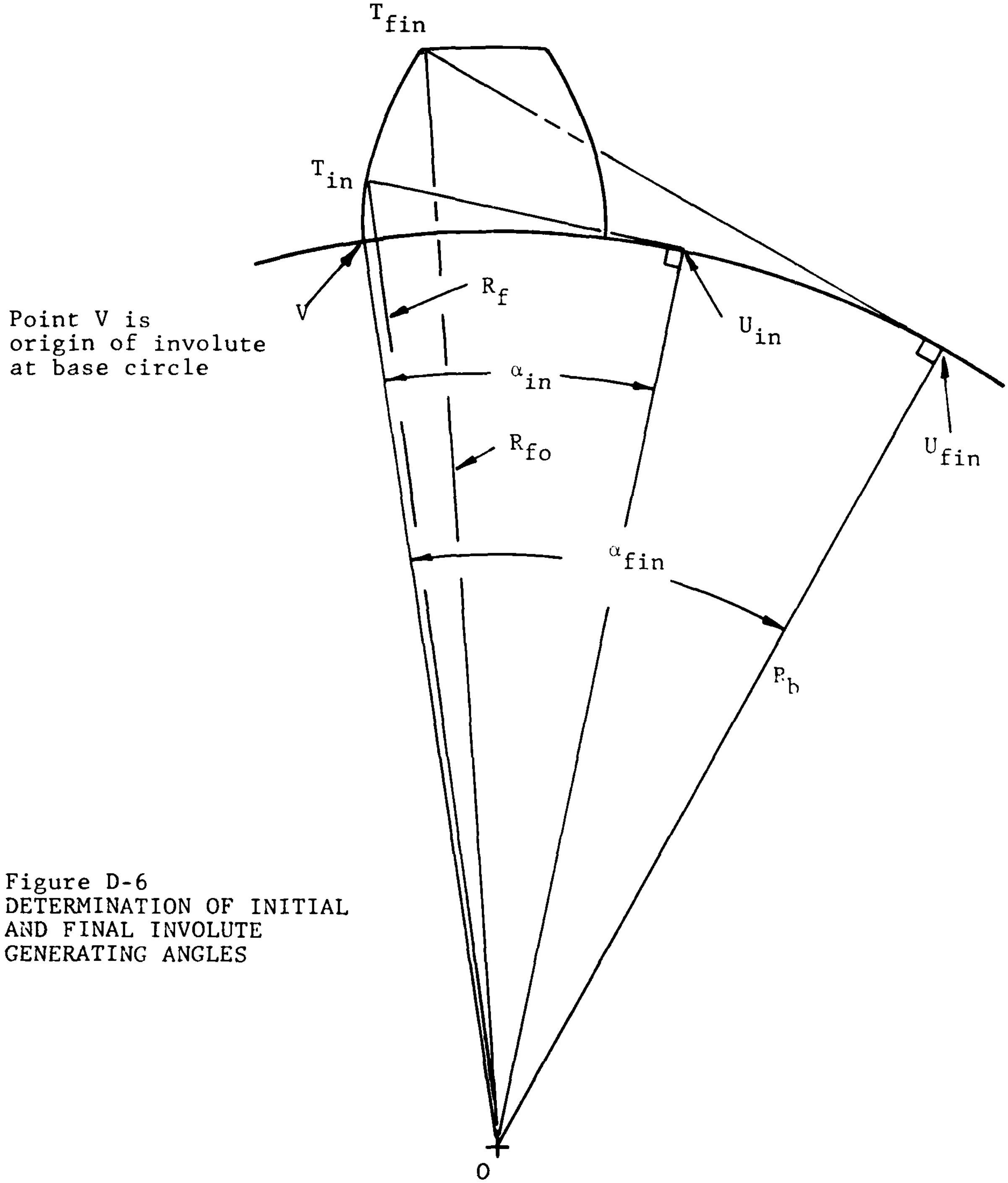


Figure D-6
DETERMINATION OF INITIAL
AND FINAL INVOLUTE
GENERATING ANGLES

Since

$$\overline{T_{in}U_{in}} = \sqrt{R_f^2 - R_b^2} \tag{D22}$$

the above becomes:

$$\alpha_{in} = \frac{\sqrt{R_f^2 - R_b^2}}{R_b} \tag{D23}$$

Similarly, with the outer form radius R_{fo} known, the final involute generating angle α_{fin} is given by :

$$\alpha_{fin} = \frac{\sqrt{R_{fo}^2 - R_b^2}}{R_b} \tag{D24}$$

APPENDIX E

GEAR STRENGTH CALCULATIONS . DETERMINATION OF LEWIS AND AGMA FACTORS

This appendix first gives a review of the origins of the Lewis gear strength formula and the associated Lewis and AGMA Geometry Factors.[+] Subsequently, the essentials of a computer determination of the Lewis Factor for any involute gear profile are developed.

[+]For more detail see: AGMA Information Sheet. Geometry Factors for Determining the Strength of the Spur, Helical,Herringborne and Bevel Gear Teeth. AGMA 226.01, American Gear Manuf. Assoc., Aug. 1970.

1. Maximum Bending Stress in a Parabolically Shaped Beam

Figure E-1 shows a cantilever beam with a parabolic cross section. The parabola originates at point O and is described by

$$y = B\,x^2, \tag{E1}$$

where B represents a constant. The beam of thickness b experiences the indicated endload F_s. Using the usual bending stress formula, the maximum bending stress σ_{max} at the abitrary section f-f becomes:

$$\sigma_{max} = \frac{M\,c}{I} = 1.5\,\frac{F_s\,y}{b\,x^2} \tag{E2}$$

where for the present case:

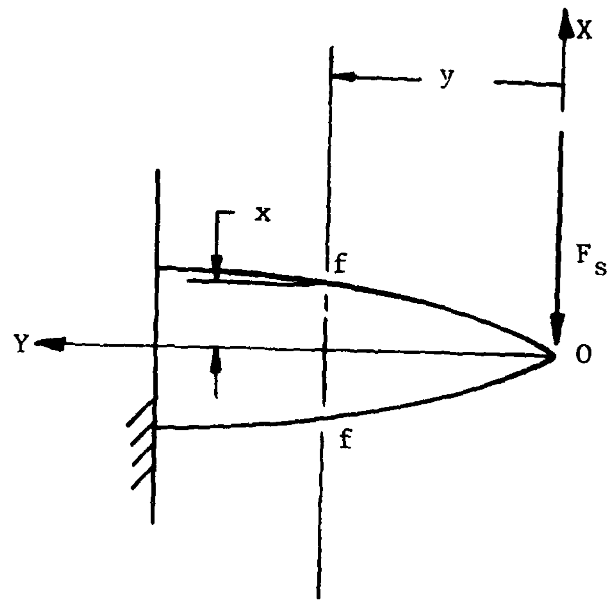
$M = F_s y$, the moment at section f-f

$c = x$, the distance to the extreme fiber of the beam

$I = \frac{b(2x)^3}{12}$, the moment of inertia of the arbitrary cross section of thickness b.

If one now substitutes the y of equ. (E1) into equ. (E2), the following expression for the maximum bending stress at any point along the beam results:

$$\sigma_{max} = F_s\,\frac{1.5\,B}{b} \tag{E3}$$



Beam Thickness = b

Figure E-1

Cantilever Beam with Parabolic

Cross Section

The above shows that, the maximum bending stress in a parabolically shaped beam is constant along the beam.

2. Derivation of Lewis Gear Strength Formula

Figure E-2 represents a typical gear tooth which is acted on by a contact load F. The line of action of this force passes through point L, the earliest possible contact with a mating tooth, at the end of the involute profile. If there is no load sharing with a second set of mating teeth, i.e. the contact ratio equals unity, this condition also produces the largest possible bending stresses at any cross section below point V, where the line of action intersects the tooth centerline.

The load angle β is defined by the line of action of force F and the normal to the tooth centerline. The bending load F_s is obtained from

$$F_s = F \cos\beta, \tag{E4}$$

and it acts normal to the centerline at point V.

Now, let point V become the origin of a parabola which is tangent to the tooth profile at some section e-e, as indicated in Figure E-2. Since, as has been shown in the previous section, the bending stress along a parabolically shaped beam is constant, section e-e must represent the location of the maximum bending

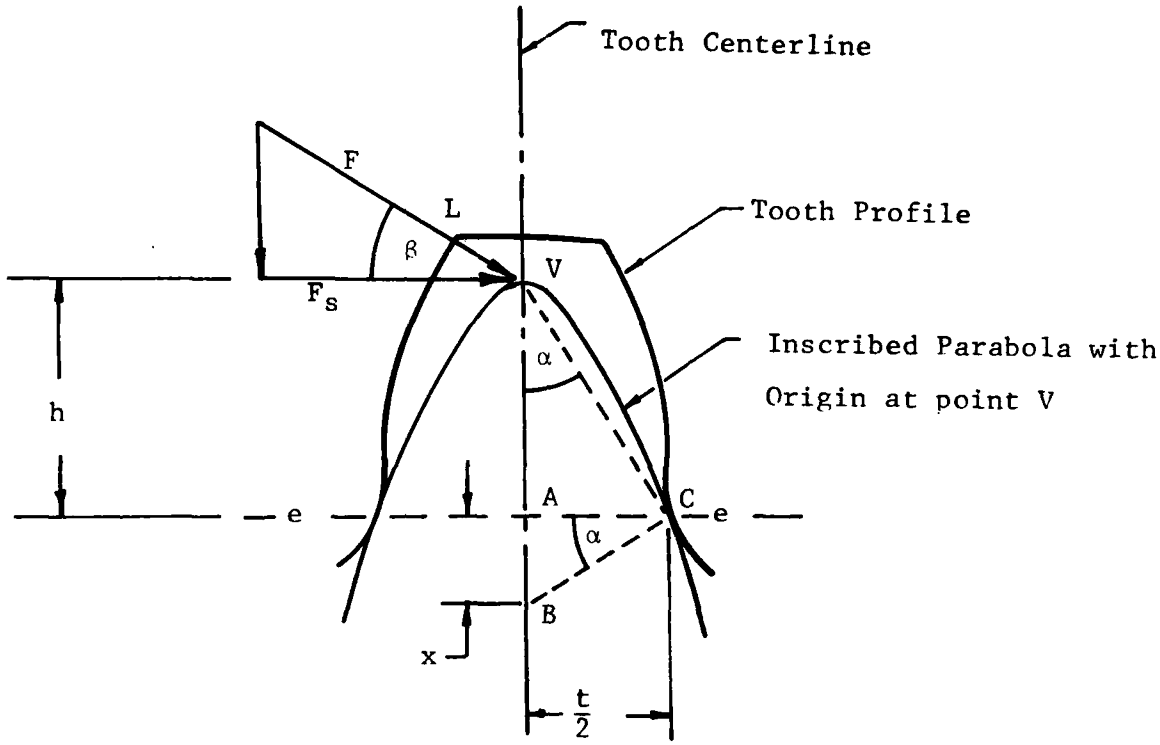


Figure E-2

Background to Lewis Formula

(Line of action of load F, as

shown, corresponds to unity contact ratio).

stress of the gear tooth. All other cross sections have portions outside the parabola and will therefore experience lower bending stresses due to the load F_s.

Thus, if one can determine the point of tangency between the parabola and the tooth profile the maximum bending stress may be found with the help of the nomenclature introduced in Figure E-2:

$$\sigma_{max} = \frac{(F_s h)(\frac{t}{2})}{\frac{b\ t^3}{12}} = \frac{6\ F_s h}{b\ t^2} \tag{E5}$$

where

$h = \overline{VA}$, the distance from point V to the tangency section e-e

$t = 2(\overline{AC})$, the tooth thickness at section e-e

The moment arm h may be expresed in terms of the distance $x = \overline{AB}$, which generally is found by graphical means. (See the aforementioned AGMA Standard 226.01). Thus, with the right triangle VCB and the resulting similar triangles AVC and ACB, one obtains the relationship:

$$\frac{x}{t/2} = \frac{t/2}{h} \tag{E6}$$

and consequently,

$$h = \frac{t^2}{4\,x} \tag{E7}$$

Equ. (E7) is now substituted into equ. (E5). This results in the following expression for the maximum bending stress in the gear tooth:

$$\sigma_{max} = \frac{F_s}{b} \left(\frac{3}{2x} \right) \tag{E8}$$

In order to make equ. (E8) as general as possible, one assumes first that the dimension x was determined for a tooth of arbitrary diametral pitch P_d. The magnitude x_1 for a tooth of unity diametral pitch will be given by:

$$x_1 = x\,P_d \tag{E9}$$

The maximum bending stress in a tooth of unity diametral pitch then becomes according to the above:

$$\sigma_{max_1} = \frac{F_s}{b\ Y} \quad , \tag{E10}$$

where the Lewis factor Y is given by:

$$Y = \frac{2\ x_1}{3} = \frac{2\ x\ P_d}{3} \tag{E11}$$

This factor may either be directly determined from a unity diametral pitch tooth, or by the indicated multiplication by P_d if x originates from a smaller tooth.

Naturally, for a given load F_s and tooth thichness b, the bending stress will be higher for teeth of larger diametral pitch. Therefore, the general form of the Lewis Gear Strength Formula becomes:

$$\sigma_{max} = \frac{F_s\ P_d}{b\ Y} \tag{E12}$$

3. Determination of Origin V of Lewis Parabola

Before the computer procedure for the determination of the point of tangency between the Lewis parabola and the tooth profile, as well as of the distance x , can be given, it is first necesary to find the distance $R_v = \overline{OV}$ from the center of the gear to point V, the origin of the Lewis parabola.

Figure E-3 shows the line of action of force F passing through the arbitrary point W_R of the involute profile. (Since the force F is always normal to the involute profile, its line of action coincides with line $\overline{U_R W_R}$). The radius $R = \overline{OW}_R$ is associated with point W_R .

The load angle β_R of this line of action with the normal to the tooth centerline is identical to the angle between the tooth centerline and the indicated base radius $\overline{OU}_R = R_b$. This later angle may be defined as follows:

$$\beta_R = \phi_R - \theta_R \tag{E13}$$

where

$$\phi_R = \cos^{-1} \frac{R_b}{R} \tag{E14}$$

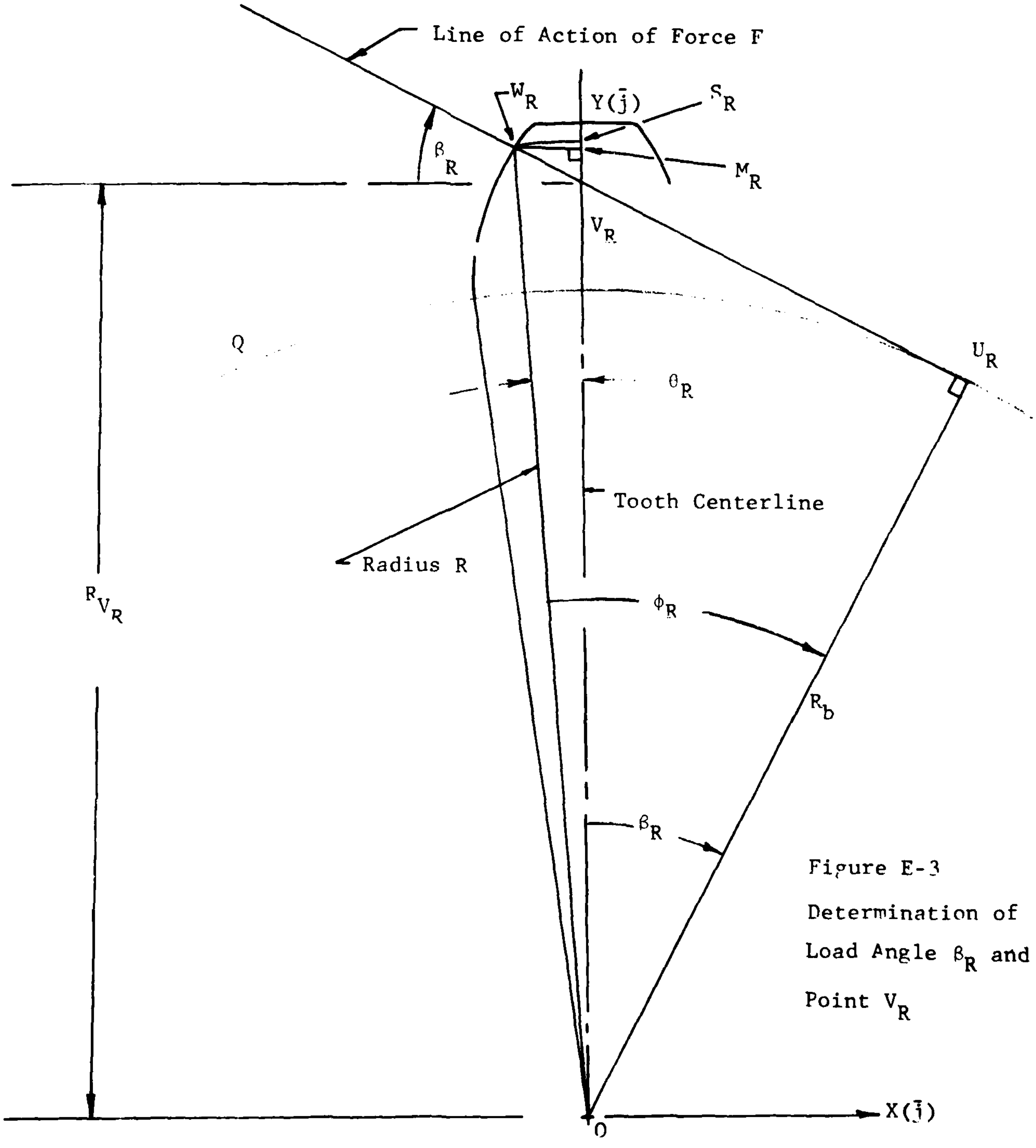


Figure E-3

Determination of Load Angle β_R and Point V_R

and

$$\theta_R = \frac{\widehat{W_R S_R}}{R} \tag{E15}$$

The above arc length is equal to one half of the circular tooth thickness T_R at radius R. To determine this tooth thickness, one makes use of the following relationship from involutometry which allows the determination of a circular tooth thickness T_2 at a radius R_2 if the tooth thickness T_1 at radius R_1 is known:

$$T_2 = T_1 \frac{R_2}{R_1} - 2R_2(\text{ INV } \phi_2 - \text{ INV } \phi_1) \tag{E16}$$

where

$$\text{INV } \phi_i = \tan \phi_i - \phi_i \tag{E17}$$

To adapt the above to the present case, it is necessary to know the actual circular tooth thickness T_{cs} at the standard pitch radius R_p of the gear. (The magnitude of T_{cs} depends on whether the gear is standard or modified). The associated angle ϕ corresponds always to the pressure angle θ of the rack cutter.

Equ. (E15) for θ_R may now be expressed with the help of equ. (E16) in the following manner:

$$\theta_R = \frac{T_R}{2R} = \frac{1}{2R} [T_{cs} \frac{R}{R_p} - 2R (INV\ \phi_R - INV\ \theta)] \tag{E18}$$

or

$$\theta_R = \frac{T_{cs}}{2R_p} - INV\ \phi_R + INV\ \theta \tag{E19}$$

Finally, Equ. (E13) for load angle β_R becomes:

$$\beta_R = \cos^{-1}(\frac{R_b}{R}) - \frac{T_{cs}}{2R_p} + INV\ \phi_R - INV\ \theta \tag{E20}$$

For the case when the contact ratio of the mesh is unity and therefore the crucial contact is made at the end of the involute, one lets $R = R_o$, the outside radius of the gear, in equ. (E20). This gives the load angle β for the Lewis parabola:

$$\beta = \cos^{-1}\left(\frac{R_b}{R_o} \right) - \frac{T_{cs}}{2R_p} + \text{INV}\ \phi_{R_o} - \text{INV}\ \theta \tag{E21}$$

where

$$\phi_{R_o} = \cos^{-1}\left(\frac{R_b}{R_o} \right) \tag{E22}$$

To determine the position of point V_R , where the line of action intersects the tooth centerline, one considers the following: (See Figure E-3)

$$R_{V_R} = \overline{OV}_R = \overline{OM}_R - \overline{M_R V_R} \tag{E23}$$

Since the line $\overline{W_R M_R}$ is normal to the tooth centerline,

$$\overline{W_R M_R} = R\sin\theta_R \ , \tag{E24}$$

while

$$\overline{OM}_R = R\cos\theta_R \tag{E25}$$

and

$$\overline{M_R V_R} = R \sin\theta_R \tan\beta_R \qquad \text{(E26)}$$

Substitution of equ's. (E25) and (E26) into equ. (E23) leads to the position of point V_R with respect to center O of the gear:

$$R_{V_R} = R\,(\cos\theta_R - \sin\theta_R \tan\beta_R) \qquad \text{(E27)}$$

For the case when $R = R_o$, the above expression becomes:

$$R_v = R_o(\cos\theta_{R_o} - \sin\theta_{R_o} \tan\beta)\,, \qquad \text{(E28)}$$

where β is given by equ. (E21) and θ_{R_o} is obtained with the help of equ. (E19) , i.e.:

$$\theta_{R_o} = \frac{T_{cs}}{2R_p} - \text{INV}\ \phi_{R_o} + \text{INV}\ \theta \qquad \text{(E29)}$$

again, $$\phi_{R_o} = \cos^{-1}\frac{R_b}{R_o} \qquad \text{(E30)}$$

4. Computer Determination of Lewis and AGMA Geometry Factors

The computer determination of the Lewis and the AGMA Geometry factors requires that the coordinates of the gear tooth profile are fully known and stored in the associated vectors X2(K) and Y2(K). Subsequent to this, the following operations are performed (See Figure E-4):

a. The distance $R_v = \overline{OV}$, of the origin V of the Lewis parabola, is found with the help of equ. (E28).

b. To accommodate the specific situation, the equation of this parabola becomes:

$$R_v - Y2(K) = B\, X_{par}^2 , \qquad \text{(E31)}$$

where X_{par} is the x-coordinate of the parabola, associated with the coordinate Y2(K). Again, as in equ. (E1), B represents the constant of a specific parabola. Since X_{par} is required, equ. (E31) becomes:

$$X_{par} = \sqrt{\frac{R_v - Y2(K)}{B}} \qquad \text{(E32)}$$

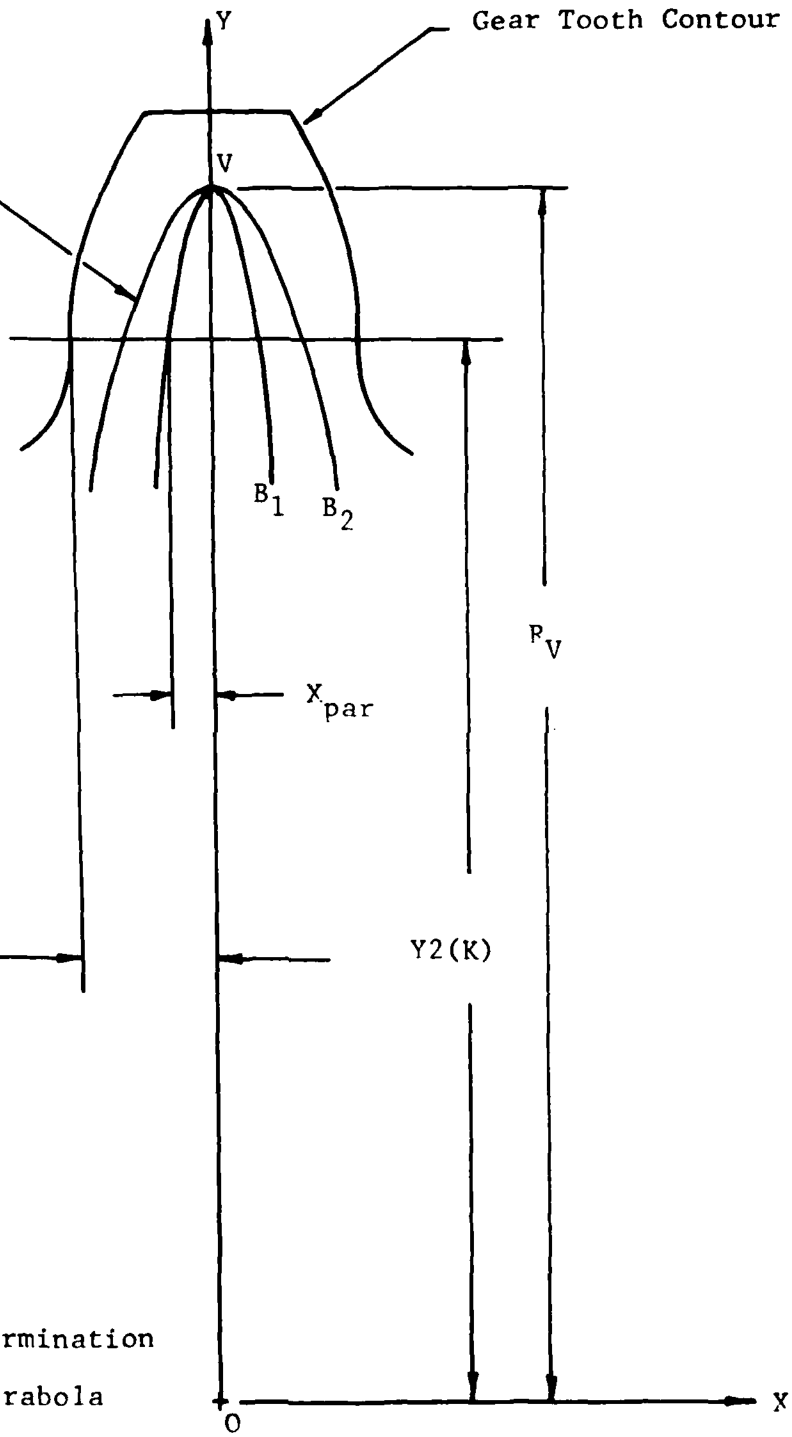


Figure E-4
Computer Determination
of Tangent Parabola

c. In order to find the tangent parabola and with that the value of the parameter x of the Lewis formula, the appropriate constant B must be determined. To this end, a comparatively large B is first chosen to make sure that the associated parabola does not contact the tooth profile. The inner parabola of Figure E-4, with the constant B_1, represents such a case. As the magnitude of B is progressively decreased, the resulting parabolae approach the tooth profile more closely. (The constant B_2 of the outer parabola of Figure E-4 is smaller than the constant B_1 of the inner one). Eventually, the tangent parabola will have the correct value of B.

d. The above process is accomplished by computing for a given value of B all X_{par} as functions of the full range of the Y2(K). Each X_{par} is compared with the corresponding value of X2(K) of the tooth profile. Whenever

$$| X2(K)| - | X_{par} | \leq 0 , \qquad \text{(E33)}$$

the correct value of B was used and the associated values of $X2(K_{tan})$ and $Y2(K_{tan})$ lie on the tangency cross section of the gear tooth. The tooth thickness t as defined by Figure E-2 then becomes:

$$t = 2\ [|\ X2(K_{tan})\ |] \qquad \text{(E34)}$$

e. Finally, the Lewis distance x of equ. (E6) may be found by:

$$x = \frac{[t/2]^2}{h} = \frac{[\ X2(K_{tan})]^2}{R_v - Y2(K_{tan})} \qquad \text{(E35)}$$

The AGMA Geometry factor Y_{AGMA} is obtained from the substitution of the above into

$$Y_{AGMA} = \frac{1}{\frac{\cos\beta}{\cos\theta}\left(\frac{1.5}{x} - \frac{\tan\beta}{2[|X2(K_{tan})|]}\right)}$$

(E36)

APPENDIX F

PROGRAM MATRIX

The present appendix describes and lists program MATRIX which is used for the determination of the sizes of the various arrays in programs LEWIS CIRCLES and LEWIS ENVELOPE. A sample of the program, together with two output pages is given in section 5 below.

1. Determination of Length of Vectors X1 and Y1
   (Used in programs LEWIS CIRCLES and LEWIS ENVELOPE.)

The vectors X1 and Y1 are used for the initial storage of the involute coordinates of the tooth profile. The common length of these vectors is determined with help of equ. (1) i.e.

$$\text{Y1-rows} = \frac{\alpha_{fin} - \alpha_{in}}{\Delta\alpha} \qquad \text{(F1)}$$

The explanation for the above nomenclature follows equ. (1) in section 2.

2. Determination of Sizes of Vector Y and Array X
   (Used mostly in program LEWIS CIRCLES.)

The number of rows, both of the vector Y and the array X, depends on the number of one one-thousandth of an inch contained in the vertical distance between the initial point of the first fillet circle and the final point of the last one.

The y-coordinate y_{in} of the first point of the first circle is that of its effective point. It is determined for $\psi = \psi_{in}$ according to equ. (B9) or equ. (B25):

$$y_{in} = (R_p - b_{eff})\cos(\tau + \psi_{in}) + (R_p \psi_{in} + a)\sin(\tau + \psi_{in}) \qquad \text{(F2)}$$

where, for an undercut tooth

$$\tau = \eta = \frac{\theta_b}{2} + \theta, \text{ according to equ. (B9)} \qquad \text{(F3)}$$

ψ_{in} = initial roll angle of rack pitch line according to equ. (D18)

For a non-undercut tooth:

$$\tau = \eta = \frac{\theta_b}{2} + \theta + \frac{b_{eff}}{R_p \sin\theta} - \tan\theta, \text{ according to equ.(B25)} \qquad \text{(F4)}$$

$\psi_{in} = 0$, according to equ. (D20)

The final point y_{fin} of the last circle is obtained according to equ. (3) or (5), i.e.:

$$y_{fin} = y_{cfin} - r_c \tag{F5}$$

y_{cfin} represents the center of the fillet circle for $\psi = \psi_{fin}$.
Then, according to equ's.(C4) or (C6):

$$y_{cfin} = (R_p - b_2)\cos(\tau + \psi_{fin}) + (R_p\psi_{fin} + a_2)\sin(\tau + \psi_{fin}) \tag{F6}$$

When the tooth is undercut the angle τ is used according to equ. (F3), otherwise equ. (F4) must be used. The angle ψ_{fin} for undercut and non-undercut teeth is the same. It is given by equ. (D14) or equ. (D19).

Thus, the number of rows of X and Y are found from:

$$\text{Y-rows} = 1000(y_{in} - y_{fin}) \text{ [in form of an integer]} \tag{F7}$$

The number of columns of the array X depends on the number of circles involved. This in turn is a function of the angular increment $\Delta\psi$ as well as ψ_{in} and ψ_{fin}.

Therefore, as in equ. (10):

$$\text{X-columns} = \frac{\psi_{in} - \psi_{fin}}{\Delta\psi} \text{ [also made into an integer]} \tag{F8}$$

3. Hand Computation of Sizes of Vectors X2 and Y2
(Used in programs LEWIS CIRCLES and LEWIS ENVELOPE)

The size of vectors X2 and Y2, which contain the final tooth profile coordinates, are not computed in program MATRIX, but may be obtained by adding the results of equ's. (F1) and (F7):

Total rows of X2 and Y2 = Y1-rows + Y-rows (F9)

The above will give an exact result for use in program LEWIS CIRCLES and a somewhat larger than needed number for program LEWIS ENVELOPE (The y-coordinates of the root are not generally computed every one one-thousandth of an inch by this routine.)

4. Description of Computer Program MATRIX (See section 5 of this Appendix)

a. Input Parameters

The following input data are required:

N	=	number of teeth in gear under consideration
BEFF	=	b_{eff} for unity diametral pitch (See Appendix B)
PD	=	P_d = 1.000, the diametral pitch
THETAD	=	θ, the pressure angle of the hob
CAPTCS	=	T_{cs}, the circular tooth thickness of the gear at

the standard pitch radius $R_p = \frac{N}{2P_d}$, in terms of $P_d = 1.000$

RC = r_c, the rack fillet radius for unity diametral pitch

KADD = Addendum constant of gear, with the magnitude of the addendum defined by KADD/PD, in terms of $P_d = 1.000$

DELPSI = $\Delta\psi$, the increment of the roll angle of the rack pitchline on the pitch circle of the gear

DELAL = $\Delta\alpha$, the increment of the involute generating angle

b. Computations

The initial computational sequence in program MATRIX is in many ways identical to that of the early parts of programs LEWIS (See section 2). Following the test which establishes whether the tooth under consideration is undercut or not, the appropriate parameters for equ's.(F1) to (F8) are computed.

The evaluation of these expressions starts in line 61 in the following sequence :

YIN = y_{in}, according to equ. (F2)

YCFIN = y_{cfin}, according to equ. (F6)

YFIN = y_{fin}, according to equ. (F5)

The integral number of rows of X and Y is found in lines 64 to 66, according to equ. (F7). The integral number of columns of array X is determined according to equ. (F8) in lines 67 an 68. The number of rows of vectors X1 and Y1, based on equ. (F1), are found in a similar manner in lines 69 and 70.

c. <u>Output Parameters</u>
(All lengths are given in inches and all angles are given in degrees)

The output of the program first states the numerical values of the input parameters N, BEFF, PD, THETAD, CAPTCS, RC, KADD, DELPSI, and DELAL.
Subsequently, it is noted whether the tooth is undercut or not. In addition, the numerical values of the following computed quantities are given:

RF = R_f

ALPHIN = α_{in}

ALPHFIN = α_{fin}

PSIIN = ψ_{in}

PSIFIN = ψ_{fin}

YIN = y_{in}

YCFIN = y_{cfin}

YFIN = y_{fin}

Finally, the number of rows of the vectors X1 and Y1, together with the size of the tooth root array X, are printed out.

5. Sample Program and Sample Output

The following pages contain a listing of program MATRIX as well as two sample outputs.

The programs were run for the same teeth as found in programs LEWIS CIRCLES and LEWIS ENVELOPE in section 3 of this report.

The input data for the first run on p. F-12 are as follows:

N	=	36,
BEFF	=	1.215 in.,
PD	=	1.000,
THETAD	=	20°,
CAPTCS	=	1.8460 in.,
RC	=	0.040 in.,
KADD	=	1.425 in.,
DELPSI	=	0.125 degrees

DELAL = 0.25 degrees

The program found that the tooth is not undercut. The various output parameters from RV toYFIN may be used for checking. Finally the array sizes are given as:

Length of Vectors X1 and Y1	:	94
Length of Vector Y	:	370
Size of Array X	:	370 x 85

The lengths of vectors X2 and Y2 are obtained by addition of the lengths of Y1 and Y, according to equ. (F9), i.e.,

$$94 + 370 = 464$$

The second run of the program on page F-13 concerns itself with an undercut 12 tooth pinion.

```
$JOB
C
C
C          *****  MATRIX  *****
C
C
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON RF,B,RB,THETA
      REAL N,KADD
      READ(5,51) N,BEFF,PD,THETAD,CAPTCS,RC
      READ(5,52) KADD
      READ(5,53) DELPSI,DELAL
   51 FORMAT(6F9.5)
   52 FORMAT(F9.5)
   53 FORMAT(2F9.5)
      WRITE(6,1)N,BEFF,PD
    1 FORMAT('1','N =',F9.5,5X,'BEFF =',F9.5,5X,'PD =',F9.5)
      WRITE(6,3)THETAD,CAPTCS,RC
    3 FORMAT(//' THETAD =',F9.5,5X,'CAPTCS =',F9.5,5X,'RC =',F9.5)
      WRITE(6,2) KADD,DELPSI,DELAL
    2 FORMAT(//' ','KADD =',F9.5,5X,'DELPSI =',F9.5,5X,'DELAL =',F9.5//)
      PI = 3.14159
      Z = PI/180.
      THETA = THETAD*Z
      RP = N/(2.*PD)
      RB = RP*DCOS(THETA)
      RO = RP+KADD/PD
      B = BEFF/PD
      THETAB = CAPTCS*DCOS(THETA)/RB+2.*(DTAN(THETA)-THETA)
      EPS = THETAB/2.D0 + THETA
      DELTA = B/(RP*DSIN(THETA)) - DTAN(THETA)
      BALLOW = RP*DSIN(THETA)*DSIN(THETA)
      IF(BEFF.GT.BALLOW) GO TO 41
      IF(BEFF.LE.BALLOW) GO TO 42
C         *********************************
C         *****   TOOTH IS UNDERCUT   *****
C         *********************************
   41 A = (RP-B)*DTAN(THETA)
      TAU = EPS
      RT = RC
      C = RB
      RF=DEKKER(RT,C,1.D-16,1.D-18,100)
      ALPHIN = DSQRT(DABS(RF*RF-RB*RB))/RB
      ALPHF = DTAN(DARCOS(RB/RC))
      GAMT = (DSQRT(DABS(RF*RF-(RP-BEFF)**2)))/RP
      PSIIN = -A/RP + GAMT
      PSIFIN = -A/RP
      WRITE(6,65)
   65 FORMAT(//' *****   TOOTH IS UNDERCUT   *****'//)
      GO TO 43
C
C         ***************************************
C         *****   TOOTH IS NOT UNDERCUT   ******
C         ***************************************
C
   42 A = B/DTAN(THETA)
      TAU = EPS + DELTA
      RF = DSQRT(DABS((RB*DTAN(THETA)-B/DSIN(THETA))**2+RB*RB))
      ALPHIN = DSQRT(DABS(RF*RF-RB*RB))/RB
      IF (ALPHIN.LE.0.001) ALPHIN = 0
```

```
      ALPHF = DTAN(DARCOS(RB/RC))
      PSIIN = 0.0
      PSIFIN = -A/RP
      WRITE(6,66)
   66 FORMAT(//' *****   TOOTH IS NOT UNDERCUT   *****'//)
   43 CONTINUE
      WRITE(6,62) RF
   62 FORMAT(//' ','RF =',F9.5//)
C
C     ***************************************
C     *****   FOR ALL TYPES OF TEETH   *****
C     ***************************************
      PSIIND = PSIIN/Z
      PSIFD = PSIFIN/Z
      ALIND = ALPHIN/Z
      ALFIND = ALPHF/Z
C
      B2 = B - RC*DSIN(THETA)
      A2 = A - RC*DCOS(THETA)
      YIN = (RP-B)*DCOS(TAU+PSIIN)+(RP*PSIIN+A)*DSIN(TAU+PSIIN)
      YCFIN = (RP-B2)*DCOS(TAU+PSIFIN)+(RP*PSIFIN+A2)*DSIN(TAU+PSIFIN)
      YFIN = YCFIN - RC
      RCW = YIN - YFIN
      RCW = RCW*1000
      IRCW = RCW
      COL = (PSIIND - PSIFD)/DELPSI
      ICOL = COL
      ROWINV = (ALPHF-ALPHIN)/(Z*DELAL)
      IRINV = ROWINV
      WRITE(6,5) ALIND,ALFIND
    5 FORMAT(//' ','ALPHIN =',F9.5,5X,'ALPHFIN =',F9.5)
      WRITE(6,86) PSIIND,PSIFD
   86 FORMAT(//' ','PSIIN =',F9.5,5X,'PSIFIN =',F9.5)
      WRITE(6,82) YIN,YCFIN,YFIN
      WRITE(6,85) IRINV
   85 FORMAT(/////' ',5X,'LENGTH OF ROWS FOR INVOLUTE VECTORS X1 AND Y1'
     1,//' ROWS =',I6)
      WRITE(6,87)
   87 FORMAT(//' ',5X,'NUMBER OF ROWS AND COLUMNS FOR TOOTH ROOT ARRAYS'
     1)
      WRITE(6,83) IRCW,ICOL
   82 FORMAT(//'0YIN=',F11.5,5X,'YCFIN=',F11.5,5X,'YFIN=',F11.5)
   83 FORMAT(//' ',' ROW=',I6,5X,' COL=',I6)
      STOP
      END

      DOUBLE PRECISION FUNCTION DEKKER(B,C,EPS,TOL,LIMIT)
C
C*********************************************************************
C
C TITLE- DEKKER'S ALGORITHM
C
C PURPOSE- TO FIND A ROOT OF A NON-LINEAR ALGEBRAIC EQUATION F(X)=0.
C DESCRIPTION OF PARAMETERS
C      B = THE LATEST ITERATE AND CLOSEST APPROXIMATION TO THE ROOT.
C      A = THE PREVIOUS ITERATE.
C      C = THE PREVIOUS OR AN OLDER ITERATE.
C COMMENTS
C      AT ALL TIMES B AND C BRACKET THE ROOT.
C      INITIALLY A IS SET EQUAL TO C.
```

```
C      USE EPS=1.D-7 AND TOL=1.D-10.
C SUBROUTINES AND/OR FUNCTION SUBPROGRAMS REQUIRED- F(X)
C*****************************************************************
       IMPLICIT REAL*8 (A-H,O-Z)
       A=C
       KOUNT=-1
       FCA=F(A)
       FCB=F(B)
       FCC=F(C)
       IF((FCB*FCC).GT.0.D0)GO TO 6
     8 KOUNT=KOUNT+1
       IF(DABS(FCB).LE.DABS(FCC))GO TO 7
       T=B
       B=C
       DEKKER=B
       C=T
       A=C
       T=FCB
       FCB=FCC
       FCC=T
       FCA=FCC
     7 IF(FCB.EQ.0.D0)RETURN
       TOL1=2.D0*EPS*DABS(B)+0.5D0*TOL
       IF(DABS(B-C).LE.2.D0*TOL1)RETURN
       IF(DABS(FCB-FCA).LT.1.D-70)RETURN
       IF(KOUNT.GE.LIMIT)GO TO 12
       DI=A-((B-A)*FCA)/(FCB-FCA)
       BP=DI
       IF(.NOT.(((C.LE.DI).AND.(DI.LE.B)).OR.((B.LE.DI).AND.(DI.LE.C))))
      1 BP=(B+C)/2.D0
       IF((((C.LE.DI).AND.(DI.LE.B)).OR.((B.LE.DI).AND.(DI.LE.C)))
      1 .AND.(DABS(DI-B).LT.TOL1))BP=B+DSIGN(TOL1,(C-B))
       IF(DABS(DI-C).LT.DABS(B-C)/4.D0)BP=(B+C)/2.D0
       A=B
       FCA=FCB
       B=BP
       DEKKER=B
       FCB=F(B)
       IF((FCB*FCC).GT.0.D0)C=A
       IF((FCB*FCC).GT.0.D0)FCC=FCA
       GO TO 8
     6 WRITE(6,15)
       STOP
    12 WRITE(6,13)
       STOP
    15 FORMAT('-','ERROR IN INPUT DATA.  F(B) HAS THE SAME SIGN AS',
      1 ' F(C)')
    13 FORMAT('-','NUMBER OF ITERATIONS HAS EXCEEDED LIMIT.  STOP COMPUTA
      1TIONS.')
       END

       DOUBLE PRECISION FUNCTION F(X)
       IMPLICIT REAL*8 (A-H,O-Z)
       COMMON RF,R,RP,THETA
       F=DATAN(DSQRT(X**2-(RP-R )**2)/(RP-R ))-DSQRT(X**2-(RP-R )**2)/RP
      1-THETA+(RP-R )*DTAN(THETA)/RP-DSQRT(X**2-RF**2)/RF+DATAN(DSQRT(X
      2**2-RF**2)/RP)
       RETURN
       END
```

```
N = 26.00000      PETI =  1.21500      PD =  1.00000

THETAD = 20.00000      CAPTCS =  1.84500      RC =  0.04000

KADD =  1.42500      DELPSI =  0.12500      DELAL =  0.25000

*****   TOOTH IS NOT UNDERCUT   *****

RF = 17.11373

ALPHIN =  8.82052      ALPHFIN = 32.35465

PSIIN =  0.00000      PSIFIN =-10.62579

YIN=   17.07761      YCFIN=   16.74754      YFIN=   16.70754

    LENGTH OF ROWS FOR INVOLUTE VECTORS X1 AND Y1
ROWS =    94

    NUMBER OF ROWS AND COLUMNS FOR TOOTH ROOT ARRAYS

 ROW=   370      COL=    85
CORE USAGE       OBJECT CODE=    8152 BYTES,ARRAY AREA=      48 BYTES,TOTAL AREA AVAILABLE=   39912  BYTES
DIAGNOSTICS        NUMBER OF ERRORS=       0, NUMBER OF WARNINGS=       0, NUMBER OF EXTENSIONS=       0
COMPILE TIME=     0.63 SEC,EXECUTION TIME=     0.05 SEC,  WATFIV - JUL 1973 V1L4      15 34.35     FRIDAY       15 MAY 81
```

```
N = 12.00000     REFF =  1.05260     PD =  1.00000

THETAL = 20.00000     CAPTCS =  1.57079     RC =  0.30000

KADD =  1.00000     DELPSI =  0.50000     DFLAL =  0.25000


*****   TOOTH IS UNDERCUT   *****


RF =  5.65550


ALPHIN =  4.49751     ALPHFIN = 42.15910

PSIIN =  8.97016     PSIFIN =-17.19548


YIN=    5.59562     YCFIN=    4.89998     YFIN=    4.59998


    LENGTH OF ROWS FOR INVOLUTE VECTORS X1 AND Y1
ROWS =   150

    NUMBER OF ROWS AND COLUMNS FOR TOOTH ROOT ARRAYS

ROW=   395     COL=    52
CORE USAGE       OBJECT CODE=    8152 BYTES,ARRAY AREA=      48 BYTES,TOTAL AREA AVAILABLE=   39912  BYTES
DIAGNOSTICS       NUMBER OF ERRORS=      0, NUMBER OF WARNINGS=      0, NUMBER OF EXTENSIONS=       0
COMPILE TIME=     0.62 SEC,EXECUTION TIME=     0.08 SEC,  WATFIV - JUL 1973 V1L4      17.27.08     FRIDAY      15 MAY 81
```

APPENDIX G

PROGRAM LEWIS CIRCLES

```
C
C
C       LEWIS CIRCLES
C
C
C       SEARCH FOR CCNB (B) THAT GIVES LEWIS PARABOLA WHICH IS
C       TANGENT TO TOOTH PROFILE
C
C
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON RP,B,RB,THETA
      DIMENSION X1(100),Y1(100)
      DIMENSION Y(400),X(400,100),X2(500),Y2(500)
      INTEGER BEGIN,FINISH
      REAL XC,XT,YT,YC,YTT,XTT,N
      REAL KADD
      READ(5,910)ISTOP
  910 FORMAT(I1)
   99 READ(5,51) N,BEFF,PD,THETAD,CAPTCS,RC
      READ(5,52) KADD
      READ(5,53) DELPSI,DELAL
      READ(5,54) DELCCN,CCNB
      READ(5,55) NRITE
      ISTOP = ISTOP - 1
   51 FORMAT(6F9.5)
   52 FORMAT(F9.5)
   53 FORMAT(2F9.5)
   54 FORMAT(2F9.5)
   55 FORMAT(I1)
      WRITE(6,1)N,BEFF,PD
    1 FORMAT('1','N =',F9.5,5X,'BEFF =',F9.5,5X,'PD =',F9.5)
      WRITE(6,3)THETAD,CAPTCS,RC
    3 FORMAT(//' THETAD =',F9.5,5X,'CAPTCS =',F9.5,5X,'RC =',F9.5)
      WRITE(6,2) KADD
    2 FORMAT(//' ','KADD =',F9.5,//)
      WRITE(6,4) DELAL,DELPSI,DELCCN,CCNB
    4 FORMAT(//' ','DELAL =',F9.5,5X,'DELPSI =',F9.5,5X,'DELCCN= ',F9.5,
     15X,'CCNB =',F9.5)
C
C
C       INITIALIZE MATRIX
C
C
      DO 77 I=1,400
      DO 78 J=1,90
      X(I,J) = -10.000
   78 CONTINUE
   77 CONTINUE
      PI = 3.14159
      Z = PI/180.
      THETA = THETAD*Z
      RP = N/(2.*PD)
      RB = RP*DCOS(THETA)
      RC = RP+KADD/PD
      B = BEFF/PD
      THETAB = (CAPTCS*DCOS(THETA))/RB + 2.*(DTAN(THETA)-THETA)
      EPS = THETAB/2.00 + THETA
      THETAC - THETAB/2
```

```
0044                EPSE = EPS/2
0045                BALLOW = RP*DSIN(THETA)*DSIN(THETA)
0046                IF(BEFF.GT.BALLOW) GO TO 41
0047                IF(BEFF.LE.BALLOW) GO TO 42
          C
          C            ********************************
          C            *****    TOOTH IS UNDERCUT  *****
          C            ********************************
          C
0048             41 A = (RF-B)*DTAN(THETA)
0049                DELTAD = 0.0
0050                TAU = EPS
0051                B1 = RC
0052                C = RB
0053                RF=DEKKER(B1,C,1.D-16,1.D-18,100)
0054                ALPHIN = DSQRT(DABS(RF*RF-RB*RB))/RB
0055                ALPHF = DTAN(DARCOS(RB/RC))
0056                GAMT = (DSQRT(DABS(RF*RF-(RP-BEFF)**2)))/RF
0057                PSIIN = -A/RP + GAMT
0058                PSIF = -A/RP
0059                WRITE(6,65)
0060             65 FORMAT(//' *****    TOOTH IS UNDERCUT    *****'//)
0061                GO TO 43
          C
          C            ************************************
          C            *****    TOOTH IS NOT UNDERCUT  *****
          C            ************************************
          C
0062             42 A = B/DTAN(THETA)
0063                DELTA = B/(RB*DSIN(THETA)) - DTAN(THETA)
0064                DELTAD = DELTA/2
0065                TAU = EPS + DELTA
0066                RF = DSQRT(DABS((RB*DTAN(THETA)-B/DSIN(THETA))**2+RB*RB))
0067                GAMT = 0.0
0068                ALPHIN = DSQRT(DABS(RF*RF-RB*RB))/RB
0069                IF (ALPHIN.LE.0.001) ALPHIN = 0
0070                ALPHF = DTAN(DARCOS(RB/RC))
0071                PSIIN = 0.0
0072                PSIF = -A/RP
0073                WRITE(6,66)
0074             66 FORMAT(//' *****    TOOTH IS NOT UNDERCUT    *****'//)
0075             43 CONTINUE
0076                WRITE(6,70) RP,RB,RC,RF
0077             70 FORMAT(' RP =',F9.5,5X,'RB =',F9.5,5X,'RO =',F9.5,5X,' RF =',F9.5/)
0078                TAUD = TAU/2
0079                GAMTD = GAMT/2
0080                WRITE(6,71) THETAD,GAMTD,EPSD,DELTAD,TAUD
0081             71 FORMAT(/' THETAE =',F9.5,5X,'GAMT =',F9.5,5X,'EPS =',F9.5,5X,'DELT
               1A =',F9.5,5X,'TAU =',F9.5)
          C
          C            ****************************************
          C            *****    FOR ALL TYPES OF TEETH    *****
          C            ****************************************
          C
0082                PSIFD = PSIF/2
0083                B2 = B - RC*DSIN(THETA)
0084                A2 = A - RC*DCOS(THETA)
0085                ALINI = ALPHIN/2
```

```
0086          ALFINC = ALPHF/2
0087          WRITE(6,5) ALINC,ALFIND
0088        5 FORMAT(//' ','ALPHIN =',F9.5,5X,'ALPHFIN =',F9.5)
        C
        C
        C
        C        INVOLUTE  PLOT
        C
        C
        C
0089          I = 1
0090          ALPHA = ALPHIN
0091       10 XI = RB*(-DSIN(THETAB*.5-ALPHA)-ALPHA*DCOS(THETAB*.5-ALPHA))
0092          YI = RB*(DCOS(THETAB*.5-ALPHA)-ALPHA*DSIN(THETAB*.5-ALPHA))
0093          X1(I) = XI
0094          Y1(I) = YI
0095          IF (ALPHA.GE.ALPHF)GO TO 20
0096          ALPHA = ALPHA + DELAL*2
0097          I = I+1
0098          IFFLV = 1
0099          GO TO 10
        C
        C
        C        REVERSE ORDER TO DESCEND
        C
        C
0100       20 DO 16 K=1,I
0101          J = I - (K-1)
0102          X2(J) = X1(K)
0103          Y2(J) = Y1(K)
0104       16 CONTINUE
        C
        C        ******************************
        C        *****    TROCHOID PLOT   *****
        C        ******************************
        C
0105          PSI = PSIIN
0106          PSID = PSI/2
0107          WRITE(6,6) PSID,PSIFD
0108        6 FORMAT(//' ','PSIIN =',F9.5,5X,'PSIFIN =',F9.5)
0109          I = 1
0110          J = 1
0111       25 XC = -(RP-B2)*DSIN(TAU+PSI)+(RP*PSI+A2)*DCOS(TAU+PSI)
0112          YC = (RP-B2)*DCOS(TAU+PSI)+(RP*PSI+A2)*DSIN(TAU+PSI)
0113          YT = (RP-B)*DCOS(TAU+PSI)+(RP*PSI+A)*DSIN(TAU+PSI)
0114          IF(I.EQ.1) GO TO 80
0115          I = 1
        C
        C        TRUNCATE VALUE OF YTROCH
        C
0116          YI = YI*1000
0117          IYI = IFIX(YI)
0118       60 TEMP = Y(I) -IYI
0119          IF(TEMP.LE.0) GO TO 90
0120          I = I + 1
0121          GO TO 60
0122       30 YT = YT*1000.
0123          IYT = IFIX(YT)
```

```
0124          90 Y(I) = IYT
0125             YII = DFLOAT(IYI)
0126             YIII = YII/1000.
0127             DIFF = YIII - (YC - RC)
0128             IF(DIFF.LE.0) GO TO 150
0129             X(I,J) = XC + DSQRT(-(YIII-YC)**2 + RC**2)
0130             I = I + 1
0131             IYI = IYT - 1
0132             GO TO 90
0133         150 PSID = PSID - DELPSI
0134             PSI = PSID*Z
0135             IF(PSID.LE.PSIFD) GO TO 500
0136             J = J + 1
0137             JFIN = J
0138             GO TO 25
           C
           C
           C
           C        SEARCH FOR MAX VALUE IN EACH ROW
           C
           C
0139         500 YCFIN = (RF-B2)*DCOS(TAL+PSIF)+(RP*PSIF+A2)*DSIN(TAL+PSIF)
0140             YFIN = YCFIN - RC
0141             I = 1
0142         501 K = I + IPREV
0143             KFIN = K
0144             X2(K) = -10.0D0
0145             DO 19 J=1,JFIN
0146             IF(X(I,J).GT.X2(K))  X2(K) = X(I,J)
0147          19 CONTINUE
0148             Y2(K) = Y(I)/1000.D0
0149             IF(Y2(K).LE.YFIN) GO TO 21
0150             I = I + 1
0151             GO TO 501
           C
           C
           C        DETERMINATION OF DISTANCE RV
           C
           C
0152          21 PHIRC = DARCOS(RB/RO)
0153             PHIRCD = PHIRC/2
0154             BETA = DARCOS(RB/RC)-(APTCS/(2*RP)+DTAN(PHIRC)-PHIRC-DTAN(THETA)+
                1THETA
0155             BETAC = BETA/2
0156             CAPTC = CAPTCS*RO/RP-2*RO*(DTAN(PHIRC)-PHIRC-DTAN(THETA)+THETA)
0157             THETAC = CAPTC/(2.*RC)
0158             THECD = THETAC/2
0159             RV = RC*(DCOS(THETAC)-DSIN(THETAC)*DTAN(BETA))
0160             WRITE(6,100) PHIRCD,BETAC,CAPTC,THECD
0161         100 FORMAT(//' PSIRC =',F9.5,5X,'BETA =',F9.5,5X,'CAPTO =',F9.5,5X,
                1'THETAC =',F9.5//)
0162             WRITE(6,101) RV
0163         101 FORMAT(' RV =',F9.5//)
           C
           C
           C        LOCATION OF POINT V IN ARRAY Y2(K)
0164             START = RV - .005
0165             I = 1
```

```
0166      102 DIFF1 = Y2(I) - START
0167          IF(DIFF1.LE.0.0) GO TO 103
0168          I = I + 1
0169          GO TO 102
        C
        C
        C         DETERMINATION OF TANGENCY POINT
        C
        C
0170      103 BEGIN = 1
0171          KFIN = KFIN - BEGIN
0172      104 DO 105 J=1,KFIN
0173          K = BEGIN + J - 1
0174          XPAR = DSQRT((RV-DABS(Y2(K)))/CONB)
0175          DIFF2 = DABS(X2(K)) - XPAR
0176          IF(DIFF2.LE.0.0) GO TO 109
0177      105 CONTINUE
0178          CONB = CONB - DELCON
0179          GO TO 104
        C
        C
        C         DETERMINATION OF LEWIS AND ACMA FACTORS
        C
        C
0180      109 EX = X2(K)**2/(RV-Y2(K))
0181          YLEWIS = 2.D0*PD*EX/3
0182          YACMA = 1.D0/(DCOS(BETA)/DCOS(THETA)*(1.5D0/EX -
             1DTAN(BETA)/(2.D0*X2(K))))
0183          WRITE(6,111) EX,YLEWIS,YACMA
0184      111 FORMAT(//' ','EX =',F9.5,5X,'YLEWIS =',F9.5,5X,'YACMA =',F9.5)
0185          WRITE(6,110) K,Y2(K),X2(K),XPAR,CONB
0186      110 FORMAT(//' TANGENCY K =',I3,5X,'Y2(KTAN) =',F9.5,5X,'X2(KTAN) =',
             1F9.6,5X,'XPAR TAN =',F9.6,5X,'CONB =',F6.3/)
0187          WRITE(6,31) NRITE
0188       31 FORMAT(//' ',10X,'NRITE =',I1/'1')
0189          IF(NRITE.EQ.0) GO TO 999
        C
        C         THIS WILL PRINT THE FULL TOOTH PROFILE:  K,X2(K),Y2(K)
        C
0190       61 DO 63 K=1,KFIN
0191          WRITE(6,64) K,Y2(K),X2(K)
0192       64 FORMAT(' K=',I4,5X,'Y2(K) =',F10.5,5X,'X2(K) =',F10.5)
0193       63 CONTINUE
0194      999 IF(ISTOP.GT.0) GO TO 99
0195          STOP
0196          END
```

```
0001          DOUBLE PRECISION FUNCTION DEKKER(B,C,EPS,TOL,LIMIT)
        C
        C*********************************************************************
        C
        C TITLE- DEKKER'S ALGORITHM
        C
        C PURPOSE- TO FIND A ROOT OF A NON-LINEAR ALGEBRAIC EQUATION F(X)=0.
        C DESCRIPTION OF PARAMETERS
        C      B = THE LATEST ITERATE AND CLOSEST APPROXIMATION TO THE ROOT.
        C      A = THE PREVIOUS ITERATE.
        C      C = THE PREVIOUS OR AN OLDER ITERATE.
        C COMMENTS
        C      AT ALL TIMES B AND C BRACKET THE ROOT.
        C      INITIALLY A IS SET EQUAL TO C.
        C      USE EPS=1.D-7 AND TOL=1.D-10.
        C SUBROUTINES AND/OR FUNCTION SUBPROGRAMS REQUIRED- F(X)
        C*********************************************************************
0002          IMPLICIT REAL*8 (A-H,O-Z)
0003          A=C
0004          KOUNT=-1
0005          FCA=F(A)
0006          FCB=F(B)
0007          FCC=F(C)
0008          IF((FCB*FCC).GT.0.D0)GO TO 6
0009        8 KOUNT=KOUNT+1
0010          IF(DABS(FCB).LE.DABS(FCC))GO TO 7
0011          T=B
0012          B=C
0013          DEKKER=B
0014          C=T
0015          A=C
0016          T=FCB
0017          FCB=FCC
0018          FCC=T
0019          FCA=FCC
0020        7 IF(FCB.EQ.0.D0)RETURN
0021          TOL1=2.D0*EPS*DABS(B)+0.5D0*TOL
0022          IF(DABS(B-C).LE.2.D0*TOL1)RETURN
0023          IF(DABS(FCB-FCA).LT.1.D-70)RETURN
0024          IF(KOUNT.GE.LIMIT)GO TO 12
0025          DI=A-((B-A)*FCA)/(FCB-FCA)
0026          BP=DI
0027          IF(.NOT.(((C.LE.DI).AND.(DI.LE.B)).OR.((B.LE.DI).AND.(DI.LE.C))))
             1 BP=(B+C)/2.D0
0028          IF((((C.LE.DI).AND.(DI.LE.B)).OR.((B.LE.DI).AND.(DI.LE.C)))
             1 .AND.(DABS(DI-B).LT.TOL1))BP=B+DSIGN(TOL1,(C-B))
0029          IF(DABS(DI-C).LT.DABS(B-C)/4.D0)BP=(B+C)/2.D0
0030          A=B
0031          FCA=FCB
0032          B=BP
0033          DEKKER=B
0034          FCB=F(B)
0035          IF((FCB*FCC).GT.0.D0)C=A
0036          IF((FCB*FCC).GT.0.D0)FCC=FCA
0037          GO TO 8
0038        6 WRITE(6,15)
0039          STOP
0040       12 WRITE(6,13)
```

```
0041          STOP
0042       15 FORMAT('-','ERROR IN INPUT DATA.  F(B) HAS THE SAME SIGN AS',
             1 ' F(C)')
0043       13 FORMAT('-','NUMBER OF ITERATIONS HAS EXCEEDED LIMIT.  STOP COMPUTA
             1TIONS.')
0044          END
```

```
0001      DOUBLE PRECISION FUNCTION F(X)
0002      IMPLICIT REAL*8 (A-H,O-Z)
0003      COMMON RP,B,RB,THETA
0004      F=DATAN(DSQRT(X**2-(RP-B )**2)/(RP-B ))-DSQRT(X**2-(RP-B )**2)/RP
         1-THETA+(RP-B )*DTAN(THETA)/RP-DSQRT(X**2-RB**2)/RB+DATAN(DSQRT(X
         2**2-RB**2)/RB)
0005      RETURN
0006      END
```

```
N = 36.CCUCC     BEFF =  1.21500     FD =  1.CCCCC

THETAC = 2C.CCCOC     CAPTCS =  1.646CC     RC =  0.C40CC

RADD =  1.425CC


DELAL =  C.25CCC     DELPSI =  C.125CC     DELCCN=  0.C0100     CCNB =  4.CCCCC

*****   TULIP IS NOT UNDERCUT   *****

RP = 18.CCCCC     RB = 16.91447     RC = 19.425CC     RF = 17.11373

THETAB =  7.58392     GAMT =  C.0          EPS = 23.79196     DELTA = -8.62052     TAU = 14.97144

ALPHIN =  8.82052     ALPHFIN = 32.35465

PSIIN =  0.0          PSIFIN =-10.62580

PSIFU = 29.45321     BETA = 28.56269     CAP10 =  0.60383     THETAC =  C.85052

RV = 19.25831


EX =  C.55278     YLEVIS =  0.36852     YAGMA =  C.36221

TANCENCY K =237     Y2(KTAN) = 16.93700     X2(KTAN) =-1.132770     XPAR TAN = 1.132784     CCNB = 1.EC9

     NRITE =1
```

K=	1	Y2(K) =	19.45433	X2(K) =	-0.28458
K=	2	Y2(K) =	19.41766	X2(K) =	-0.30462
K=	3	Y2(K) =	19.38118	X2(K) =	-0.32435
K=	4	Y2(K) =	19.34430	X2(K) =	-0.34376
K=	5	Y2(K) =	19.30882	X2(K) =	-0.36287
K=	6	Y2(K) =	19.27254	X2(K) =	-0.38167
K=	7	Y2(K) =	19.23727	X2(K) =	-0.40016
K=	8	Y2(K) =	19.20180	X2(K) =	-0.41835
K=	9	Y2(K) =	19.16654	X2(K) =	-0.43625
K=	10	Y2(K) =	19.13149	X2(K) =	-0.45384
K=	11	Y2(K) =	19.09665	X2(K) =	-0.47113
K=	12	Y2(K) =	19.06203	X2(K) =	-0.48814
K=	13	Y2(K) =	19.02762	X2(K) =	-0.50485
K=	14	Y2(K) =	18.99343	X2(K) =	-0.52127
K=	15	Y2(K) =	18.95946	X2(K) =	-0.53740
K=	16	Y2(K) =	18.92571	X2(K) =	-0.55325
K=	17	Y2(K) =	18.89218	X2(K) =	-0.56881
K=	18	Y2(K) =	18.85888	X2(K) =	-0.58410
K=	19	Y2(K) =	18.82581	X2(K) =	-0.59910
K=	20	Y2(K) =	18.79296	X2(K) =	-0.61383
K=	21	Y2(K) =	18.76035	X2(K) =	-0.62829
K=	22	Y2(K) =	18.72796	X2(K) =	-0.64247
K=	23	Y2(K) =	18.69582	X2(K) =	-0.65639
K=	24	Y2(K) =	18.66390	X2(K) =	-0.67003
K=	25	Y2(K) =	18.63223	X2(K) =	-0.68342
K=	26	Y2(K) =	18.60079	X2(K) =	-0.69654
K=	27	Y2(K) =	18.56960	X2(K) =	-0.70940
K=	28	Y2(K) =	18.53864	X2(K) =	-0.72200
K=	29	Y2(K) =	18.50793	X2(K) =	-0.73435
K=	30	Y2(K) =	18.47747	X2(K) =	-0.74644
K=	31	Y2(K) =	18.44725	X2(K) =	-0.75829
K=	32	Y2(K) =	18.41729	X2(K) =	-0.76988
K=	33	Y2(K) =	18.38757	X2(K) =	-0.78123
K=	34	Y2(K) =	18.35810	X2(K) =	-0.79234
K=	35	Y2(K) =	18.32889	X2(K) =	-0.80320
K=	36	Y2(K) =	18.29994	X2(K) =	-0.81383
K=	37	Y2(K) =	18.27124	X2(K) =	-0.82422
K=	38	Y2(K) =	18.24280	X2(K) =	-0.83438
K=	39	Y2(K) =	18.21462	X2(K) =	-0.84431
K=	40	Y2(K) =	18.18670	X2(K) =	-0.85400
K=	41	Y2(K) =	18.15904	X2(K) =	-0.86347
K=	42	Y2(K) =	18.13165	X2(K) =	-0.87272
K=	43	Y2(K) =	18.10452	X2(K) =	-0.88175
K=	44	Y2(K) =	18.07766	X2(K) =	-0.89056
K=	45	Y2(K) =	18.05106	X2(K) =	-0.89915
K=	46	Y2(K) =	18.02474	X2(K) =	-0.90752
K=	47	Y2(K) =	17.99869	X2(K) =	-0.91569
K=	48	Y2(K) =	17.97291	X2(K) =	-0.92365
K=	49	Y2(K) =	17.94740	X2(K) =	-0.93140
K=	50	Y2(K) =	17.92217	X2(K) =	-0.93895
K=	51	Y2(K) =	17.89722	X2(K) =	-0.94629
K=	52	Y2(K) =	17.87254	X2(K) =	-0.95344
K=	53	Y2(K) =	17.84814	X2(K) =	-0.96039
K=	54	Y2(K) =	17.82402	X2(K) =	-0.96715
K=	55	Y2(K) =	17.80018	X2(K) =	-0.97372
K=	56	Y2(K) =	17.77662	X2(K) =	-0.98010
K=	57	Y2(K) =	17.75[illegible]	X2(K) =	[illegible]
K=	58	Y2(K) =	17.7[illegible]37	X2(K) =	[illegible]
K=	59	Y2(K) =	[illegible]	X2(K) =	[illegible]
K=	60	Y2(K) =	[illegible]	X2(K) =	-1.[illegible]

K=	61	Y2(K) =	17.66313	X2(K) =	-1.00926
K=	62	Y2(K) =	17.64125	X2(K) =	-1.01457
K=	63	Y2(K) =	17.61974	X2(K) =	-1.01970
K=	64	Y2(K) =	17.59849	X2(K) =	-1.02467
K=	65	Y2(K) =	17.57753	X2(K) =	-1.02947
K=	66	Y2(K) =	17.55686	X2(K) =	-1.03411
K=	67	Y2(K) =	17.53648	X2(K) =	-1.03859
K=	68	Y2(K) =	17.51640	X2(K) =	-1.04292
K=	69	Y2(K) =	17.49662	X2(K) =	-1.04709
K=	70	Y2(K) =	17.47714	X2(K) =	-1.05111
K=	71	Y2(K) =	17.45795	X2(K) =	-1.05458
K=	72	Y2(K) =	17.43906	X2(K) =	-1.05870
K=	73	Y2(K) =	17.42047	X2(K) =	-1.06228
K=	74	Y2(K) =	17.40219	X2(K) =	-1.06572
K=	75	Y2(K) =	17.38420	X2(K) =	-1.06902
K=	76	Y2(K) =	17.36652	X2(K) =	-1.07219
K=	77	Y2(K) =	17.34914	X2(K) =	-1.07523
K=	78	Y2(K) =	17.33207	X2(K) =	-1.07813
K=	79	Y2(K) =	17.31530	X2(K) =	-1.08091
K=	80	Y2(K) =	17.29884	X2(K) =	-1.08356
K=	81	Y2(K) =	17.28268	X2(K) =	-1.08609
K=	82	Y2(K) =	17.26683	X2(K) =	-1.08850
K=	83	Y2(K) =	17.25129	X2(K) =	-1.09080
K=	84	Y2(K) =	17.23606	X2(K) =	-1.09298
K=	85	Y2(K) =	17.22114	X2(K) =	-1.09505
K=	86	Y2(K) =	17.20653	X2(K) =	-1.09702
K=	87	Y2(K) =	17.19223	X2(K) =	-1.09887
K=	88	Y2(K) =	17.17824	X2(K) =	-1.10063
K=	89	Y2(K) =	17.16456	X2(K) =	-1.10229
K=	90	Y2(K) =	17.15119	X2(K) =	-1.10385
K=	91	Y2(K) =	17.13814	X2(K) =	-1.10531
K=	92	Y2(K) =	17.12541	X2(K) =	-1.10668
K=	93	Y2(K) =	17.11298	X2(K) =	-1.10797
K=	94	Y2(K) =	17.10088	X2(K) =	-1.10917
K=	95	Y2(K) =	17.08908	X2(K) =	-1.11028
K=	96	Y2(K) =	17.07761	X2(K) =	-1.11132
K=	97	Y2(K) =	17.07700	X2(K) =	-1.11138
K=	98	Y2(K) =	17.07600	X2(K) =	-1.11149
K=	99	Y2(K) =	17.07500	X2(K) =	-1.11163
K=	100	Y2(K) =	17.07400	X2(K) =	-1.11180
K=	101	Y2(K) =	17.07300	X2(K) =	-1.11199
K=	102	Y2(K) =	17.07200	X2(K) =	-1.11222
K=	103	Y2(K) =	17.07100	X2(K) =	-1.11246
K=	104	Y2(K) =	17.07000	X2(K) =	-1.11274
K=	105	Y2(K) =	17.06900	X2(K) =	-1.11211
K=	106	Y2(K) =	17.06800	X2(K) =	-1.11224
K=	107	Y2(K) =	17.06700	X2(K) =	-1.11239
K=	108	Y2(K) =	17.06600	X2(K) =	-1.11257
K=	109	Y2(K) =	17.06500	X2(K) =	-1.11277
K=	110	Y2(K) =	17.06400	X2(K) =	-1.11300
K=	111	Y2(K) =	17.06300	X2(K) =	-1.11327
K=	112	Y2(K) =	17.06200	X2(K) =	-1.11279
K=	113	Y2(K) =	17.06100	X2(K) =	-1.11290
K=	114	Y2(K) =	17.06000	X2(K) =	-1.11304
K=	115	Y2(K) =	17.05900	X2(K) =	-1.11320
K=	116	Y2(K) =	17.05800	X2(K) =	-1.11339
K=	117	Y2(K) =	17.05700	X2(K) =	-1.11361
K=	118	Y2(K) =	17.05600	X2(K) =	-1.11358
K=	119	Y2(K) =	17.05500	X2(K) =	-1.11413
K=	120	Y2(K) =	17.05400	X2(K) =	-1.11462
K=	121	Y2(K) =	17.05300	X2(K) =	-1.11374

K=	122	Y2(K) =	17.05200		X2(K) =	-1.11390
K=	123	Y2(K) =	17.05100		X2(K) =	-1.11408
K=	124	Y2(K) =	17.05000		X2(K) =	-1.11429
K=	125	Y2(K) =	17.04500		X2(K) =	-1.11452
K=	126	Y2(K) =	17.04800		X2(K) =	-1.11478
K=	127	Y2(K) =	17.04700		X2(K) =	-1.11438
K=	128	Y2(K) =	17.04600		X2(K) =	-1.11450
K=	129	Y2(K) =	17.04500		X2(K) =	-1.11465
K=	130	Y2(K) =	17.04400		X2(K) =	-1.11482
K=	131	Y2(K) =	17.04300		X2(K) =	-1.11502
K=	132	Y2(K) =	17.04200		X2(K) =	-1.11524
K=	133	Y2(K) =	17.04100		X2(K) =	-1.11550
K=	134	Y2(K) =	17.04000		X2(K) =	-1.11520
K=	135	Y2(K) =	17.03900		X2(K) =	-1.11531
K=	136	Y2(K) =	17.03800		X2(K) =	-1.11545
K=	137	Y2(K) =	17.03700		X2(K) =	-1.11562
K=	138	Y2(K) =	17.03600		X2(K) =	-1.11581
K=	139	Y2(K) =	17.03500		X2(K) =	-1.11603
K=	140	Y2(K) =	17.03400		X2(K) =	-1.11627
K=	141	Y2(K) =	17.03300		X2(K) =	-1.11654
K=	142	Y2(K) =	17.03200		X2(K) =	-1.11617
K=	143	Y2(K) =	17.03100		X2(K) =	-1.11631
K=	144	Y2(K) =	17.03000		X2(K) =	-1.11646
K=	145	Y2(K) =	17.02900		X2(K) =	-1.11665
K=	146	Y2(K) =	17.02800		X2(K) =	-1.11686
K=	147	Y2(K) =	17.02700		X2(K) =	-1.11710
K=	148	Y2(K) =	17.02600		X2(K) =	-1.11737
K=	149	Y2(K) =	17.02500		X2(K) =	-1.11708
K=	150	Y2(K) =	17.02400		X2(K) =	-1.11721
K=	151	Y2(K) =	17.02300		X2(K) =	-1.11737
K=	152	Y2(K) =	17.02200		X2(K) =	-1.11755
K=	153	Y2(K) =	17.02100		X2(K) =	-1.11776
K=	154	Y2(K) =	17.02000		X2(K) =	-1.11800
K=	155	Y2(K) =	17.01900		X2(K) =	-1.11826
K=	156	Y2(K) =	17.01800		X2(K) =	-1.11803
K=	157	Y2(K) =	17.01700		X2(K) =	-1.11816
K=	158	Y2(K) =	17.01600		X2(K) =	-1.11832
K=	159	Y2(K) =	17.01500		X2(K) =	-1.11851
K=	160	Y2(K) =	17.01400		X2(K) =	-1.11872
K=	161	Y2(K) =	17.01300		X2(K) =	-1.11896
K=	162	Y2(K) =	17.01200		X2(K) =	-1.11922
K=	163	Y2(K) =	17.01100		X2(K) =	-1.11903
K=	164	Y2(K) =	17.01000		X2(K) =	-1.11916
K=	165	Y2(K) =	17.00900		X2(K) =	-1.11933
K=	166	Y2(K) =	17.00800		X2(K) =	-1.11951
K=	167	Y2(K) =	17.00700		X2(K) =	-1.11973
K=	168	Y2(K) =	17.00600		X2(K) =	-1.11996
K=	169	Y2(K) =	17.00500		X2(K) =	-1.12023
K=	170	Y2(K) =	17.00400		X2(K) =	-1.12007
K=	171	Y2(K) =	17.00300		X2(K) =	-1.12021
K=	172	Y2(K) =	17.00200		X2(K) =	-1.12038
K=	173	Y2(K) =	17.00100		X2(K) =	-1.12057
K=	174	Y2(K) =	17.00000		X2(K) =	-1.12076
K=	175	Y2(K) =	[illegible]		X2(K) =	-1.12133
K=	176	Y2(K) =	16.99800		X2(K) =	-1.12141
K=	177	Y2(K) =	16.99700		X2(K) =	-1.12117
K=	178	Y2(K) =	16.99600		X2(K) =	-1.12131
K=	179	Y2(K) =	16.99500		X2(K) =	-1.12148
K=	180	Y2(K) =	[illegible]		X2(K) =	[illegible]
K=	181	Y2(K) =	[illegible]		X2(K) =	[illegible]
K=	182	Y2(K) =	[illegible]		X2(K) =	[illegible]

K=	183	Y2(K) =	16.99100	X2(K) =	-1.12218
K=	184	Y2(K) =	16.99000	X2(K) =	-1.12231
K=	185	Y2(K) =	16.98900	X2(K) =	-1.12246
K=	186	Y2(K) =	16.98800	X2(K) =	-1.12264
K=	187	Y2(K) =	16.98700	X2(K) =	-1.12285
K=	188	Y2(K) =	16.98600	X2(K) =	-1.12308
K=	189	Y2(K) =	16.98500	X2(K) =	-1.12335
K=	190	Y2(K) =	16.98400	X2(K) =	-1.12336
K=	191	Y2(K) =	16.98300	X2(K) =	-1.12350
K=	192	Y2(K) =	16.98200	X2(K) =	-1.12367
K=	193	Y2(K) =	16.98100	X2(K) =	-1.12386
K=	194	Y2(K) =	16.98000	X2(K) =	-1.12408
K=	195	Y2(K) =	16.97900	X2(K) =	-1.12432
K=	196	Y2(K) =	16.97800	X2(K) =	-1.12460
K=	197	Y2(K) =	16.97700	X2(K) =	-1.12459
K=	198	Y2(K) =	16.97600	X2(K) =	-1.12474
K=	199	Y2(K) =	16.97500	X2(K) =	-1.12492
K=	200	Y2(K) =	16.97400	X2(K) =	-1.12513
K=	201	Y2(K) =	16.97300	X2(K) =	-1.12536
K=	202	Y2(K) =	16.97200	X2(K) =	-1.12562
K=	203	Y2(K) =	16.97100	X2(K) =	-1.12573
K=	204	Y2(K) =	16.97000	X2(K) =	-1.12587
K=	205	Y2(K) =	16.96900	X2(K) =	-1.12604
K=	206	Y2(K) =	16.96800	X2(K) =	-1.12624
K=	207	Y2(K) =	16.96700	X2(K) =	-1.12646
K=	208	Y2(K) =	16.96600	X2(K) =	-1.12671
K=	209	Y2(K) =	16.96500	X2(K) =	-1.12698
K=	210	Y2(K) =	16.96400	X2(K) =	-1.12705
K=	211	Y2(K) =	16.96300	X2(K) =	-1.12721
K=	212	Y2(K) =	16.96200	X2(K) =	-1.12740
K=	213	Y2(K) =	16.96100	X2(K) =	-1.12761
K=	214	Y2(K) =	16.96000	X2(K) =	-1.12785
K=	215	Y2(K) =	16.95900	X2(K) =	-1.12812
K=	216	Y2(K) =	16.95800	X2(K) =	-1.12828
K=	217	Y2(K) =	16.95700	X2(K) =	-1.12844
K=	218	Y2(K) =	16.95600	X2(K) =	-1.12862
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K=	221	Y2(K) =	16.95300	X2(K) =	-1.12932
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K= 460	Y2(K) = 16.71400	X2(K) = -1.27545

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N = 12.00000     BEFF =  1.05260     PD =  1.00000

THETAC = 20.00C00     CAPTCS =  1.57079     RC =  0.30000

KACC =  1.00000


DELAL =  0.250C0     CELPSI =  0.50000     DELCON=   0.0010C     CONA =  4.00000

*****   TCCTH IS UNDERCUT   *****

RP =  6.00000     RB =  5.63816     RO =  7.00000     RF =  5.65550

THETAB = 16.70787     GAMT = 26.16565     EPS = 28.35393     DELTA =  0.0        TAU = 28.35393

ALPHIN =  4.49751     ALPHFIN = 42.15911

PSIIN =  8.97017     PSIFIN =-17.19548

PHIRC = 36.34621     BETA = 33.80518     CAPTO =  0.62089     THETAO =  2.54104

RV =  6.78532


EX =  0.34446     YLEWIS =  0.22964     YAGMA =  0.23640

TANGENCY K =729     Y2(KTAN) =  5.01900     X2(KTAN) =-0.78C016     XPAR TAN = 0.780030     CONB = 2.903

          NRITE =1
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K=	2	Y2(K) =	6.98340	X2(K) =	-0.31683
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K=	4	Y2(K) =	6.95347	X2(K) =	-0.33656
K=	5	Y2(K) =	6.93858	X2(K) =	-0.34624
K=	6	Y2(K) =	6.92373	X2(K) =	-0.35580
K=	7	Y2(K) =	6.90893	X2(K) =	-0.36523
K=	8	Y2(K) =	6.89418	X2(K) =	-0.37454
K=	9	Y2(K) =	6.87949	X2(K) =	-0.38373
K=	10	Y2(K) =	6.86484	X2(K) =	-0.39280
K=	11	Y2(K) =	6.85025	X2(K) =	-0.40175
K=	12	Y2(K) =	6.83570	X2(K) =	-0.41058
K=	13	Y2(K) =	6.82122	X2(K) =	-0.41930
K=	14	Y2(K) =	6.80678	X2(K) =	-0.42789
K=	15	Y2(K) =	6.79240	X2(K) =	-0.43636
K=	16	Y2(K) =	6.77808	X2(K) =	-0.44472
K=	17	Y2(K) =	6.76382	X2(K) =	-0.45297
K=	18	Y2(K) =	6.74961	X2(K) =	-0.46109
K=	19	Y2(K) =	6.73546	X2(K) =	-0.46911
K=	20	Y2(K) =	6.72137	X2(K) =	-0.47700
K=	21	Y2(K) =	6.70733	X2(K) =	-0.48479
K=	22	Y2(K) =	6.69336	X2(K) =	-0.49246
K=	23	Y2(K) =	6.67945	X2(K) =	-0.50002
K=	24	Y2(K) =	6.66560	X2(K) =	-0.50746
K=	25	Y2(K) =	6.65181	X2(K) =	-0.51480
K=	26	Y2(K) =	6.63809	X2(K) =	-0.52203
K=	27	Y2(K) =	6.62443	X2(K) =	-0.52914
K=	28	Y2(K) =	6.61084	X2(K) =	-0.53615
K=	29	Y2(K) =	6.59731	X2(K) =	-0.54305
K=	30	Y2(K) =	6.58384	X2(K) =	-0.54984
K=	31	Y2(K) =	6.57044	X2(K) =	-0.55653
K=	32	Y2(K) =	6.55711	X2(K) =	-0.56311
K=	33	Y2(K) =	6.54385	X2(K) =	-0.56958
K=	34	Y2(K) =	6.53066	X2(K) =	-0.57595
K=	35	Y2(K) =	6.51753	X2(K) =	-0.58222
K=	36	Y2(K) =	6.50448	X2(K) =	-0.58838
K=	37	Y2(K) =	6.49149	X2(K) =	-0.59444
K=	38	Y2(K) =	6.47858	X2(K) =	-0.60040
K=	39	Y2(K) =	6.46574	X2(K) =	-0.60625
K=	40	Y2(K) =	6.45297	X2(K) =	-0.61201
K=	41	Y2(K) =	6.44027	X2(K) =	-0.61767
K=	42	Y2(K) =	6.42765	X2(K) =	-0.62323
K=	43	Y2(K) =	6.41510	X2(K) =	-0.62869
K=	44	Y2(K) =	6.40263	X2(K) =	-0.63405
K=	45	Y2(K) =	6.39023	X2(K) =	-0.63932
K=	46	Y2(K) =	6.37791	X2(K) =	-0.644[illegible]
K=	47	Y2(K) =	6.36566	X2(K) =	-0.64957
K=	48	Y2(K) =	6.35349	X2(K) =	-0.65455
K=	49	Y2(K) =	6.34140	X2(K) =	-0.65944
K=	50	Y2(K) =	6.32939	X2(K) =	-0.66424
K=	51	Y2(K) =	6.31746	X2(K) =	-0.66894
K=	52	Y2(K) =	6.30561	X2(K) =	-0.67356
K=	53	Y2(K) =	6.29384	X2(K) =	-0.67808
K=	54	Y2(K) =	6.28214	X2(K) =	-0.68251
K=	55	Y2(K) =	6.27053	X2(K) =	-0.68686
K=	56	Y2(K) =	6.25900	X2(K) =	-0.69112
K=	57	Y2(K) =	6.24756	X2(K) =	-0.69529
K=	58	Y2(K) =	6.23620	X2(K) =	-0.69937
K=	59	Y2(K) =	6.22492	X2(K) =	-0.70337
K=	60	Y2(K) =	6.21372	X2(K) =	-0.70728
K=	61	Y2(K) =	6.20261	X2(K) =	-0.71111
K=	62	Y2(K) =	6.19158	X2(K) =	-0.71486

K= 63	Y2(K) =	6.18064	X2(K) = -0.71852
K= 64	Y2(K) =	6.16979	X2(K) = -0.72211
K= 65	Y2(K) =	6.15902	X2(K) = -0.72561
K= 66	Y2(K) =	6.14834	X2(K) = -0.72903
K= 67	Y2(K) =	6.13774	X2(K) = -0.73238
K= 68	Y2(K) =	6.12724	X2(K) = -0.73564
K= 69	Y2(K) =	6.11682	X2(K) = -0.73883
K= 70	Y2(K) =	6.10649	X2(K) = -0.74194
K= 71	Y2(K) =	6.09625	X2(K) = -0.74498
K= 72	Y2(K) =	6.08611	X2(K) = -0.74794
K= 73	Y2(K) =	6.07605	X2(K) = -0.75083
K= 74	Y2(K) =	6.06608	X2(K) = -0.75364
K= 75	Y2(K) =	6.05620	X2(K) = -0.75639
K= 76	Y2(K) =	6.04642	X2(K) = -0.75906
K= 77	Y2(K) =	6.03673	X2(K) = -0.76166
K= 78	Y2(K) =	6.02713	X2(K) = -0.76419
K= 79	Y2(K) =	6.01762	X2(K) = -0.76665
K= 80	Y2(K) =	6.00820	X2(K) = -0.76905
K= 81	Y2(K) =	5.99888	X2(K) = -0.77137
K= 82	Y2(K) =	5.98966	X2(K) = -0.77363
K= 83	Y2(K) =	5.98053	X2(K) = -0.77583
K= 84	Y2(K) =	5.97149	X2(K) = -0.77796
K= 85	Y2(K) =	5.96255	X2(K) = -0.78003
K= 86	Y2(K) =	5.95371	X2(K) = -0.78203
K= 87	Y2(K) =	5.94496	X2(K) = -0.78397
K= 88	Y2(K) =	5.93630	X2(K) = -0.78586
K= 89	Y2(K) =	5.92775	X2(K) = -0.78768
K= 90	Y2(K) =	5.91929	X2(K) = -0.78944
K= 91	Y2(K) =	5.91093	X2(K) = -0.79114
K= 92	Y2(K) =	5.90267	X2(K) = -0.79279
K= 93	Y2(K) =	5.89450	X2(K) = -0.79438
K= 94	Y2(K) =	5.88644	X2(K) = -0.79591
K= 95	Y2(K) =	5.87847	X2(K) = -0.79739
K= 96	Y2(K) =	5.87060	X2(K) = -0.79882
K= 97	Y2(K) =	5.86283	X2(K) = -0.80019
K= 98	Y2(K) =	5.85516	X2(K) = -0.80151
K= 99	Y2(K) =	5.84760	X2(K) = -0.80278
K= 100	Y2(K) =	5.84013	X2(K) = -0.80400
K= 101	Y2(K) =	5.83276	X2(K) = -0.80517
K= 102	Y2(K) =	5.82550	X2(K) = -0.80629
K= 103	Y2(K) =	5.81833	X2(K) = -0.80736
K= 104	Y2(K) =	5.81127	X2(K) = -0.80839
K= 105	Y2(K) =	5.80431	X2(K) = -0.80937
K= 106	Y2(K) =	5.79745	X2(K) = -0.81030
K= 107	Y2(K) =	5.79069	X2(K) = -0.81120
K= 108	Y2(K) =	5.78404	X2(K) = -0.81205
K= 109	Y2(K) =	5.77749	X2(K) = -0.81285
K= 110	Y2(K) =	5.77104	X2(K) = -0.81362
K= 111	Y2(K) =	5.76469	X2(K) = -0.81434
K= 112	Y2(K) =	5.75845	X2(K) = -0.81503
K= 113	Y2(K) =	5.75232	X2(K) = -0.81567
K= 114	Y2(K) =	5.74628	X2(K) = -0.81628
K= 115	Y2(K) =	5.74035	X2(K) = -0.81686
K= 116	Y2(K) =	5.73453	X2(K) = -0.81739
K= 117	Y2(K) =	5.72881	X2(K) = -0.81790
K= 118	Y2(K) =	5.72319	X2(K) = -0.81836
K= 119	Y2(K) =	5.71768	X2(K) = -0.81880
K= 120	Y2(K) =	5.71228	X2(K) = -0.81920
K= 121	Y2(K) =	5.70698	X2(K) = -0.81958
K= 122	Y2(K) =	5.70179	X2(K) = -0.81992
K= 123	Y2(K) =	5.69670	X2(K) = -0.82023
K= 124	Y2(K) =	5.69172	X2(K) = -0.82052
K= 125	Y2(K) =	5.68684	X2(K) = -0.82077
K= 126	Y2(K) =	5.68207	X2(K) = -0.82100
K= 127	Y2(K) =	5.67741	X2(K) = -0.82121
K= 128	Y2(K) =	5.67285	X2(K) = -0.82139

K=	129	Y2(K) =	5.66840	X2(K) =	-0.82155
K=	130	Y2(K) =	5.66405	X2(K) =	-0.82168
K=	131	Y2(K) =	5.65982	X2(K) =	-0.82179
K=	132	Y2(K) =	5.65569	X2(K) =	-0.82188
K=	133	Y2(K) =	5.65166	X2(K) =	-0.82196
K=	134	Y2(K) =	5.64775	X2(K) =	-0.82201
K=	135	Y2(K) =	5.64394	X2(K) =	-0.82204
K=	136	Y2(K) =	5.64023	X2(K) =	-0.82206
K=	137	Y2(K) =	5.63664	X2(K) =	-0.82206
K=	138	Y2(K) =	5.63315	X2(K) =	-0.82205
K=	139	Y2(K) =	5.62977	X2(K) =	-0.82202
K=	140	Y2(K) =	5.62650	X2(K) =	-0.82198
K=	141	Y2(K) =	5.62333	X2(K) =	-0.82192
K=	142	Y2(K) =	5.62028	X2(K) =	-0.82186
K=	143	Y2(K) =	5.61733	X2(K) =	-0.82178
K=	144	Y2(K) =	5.61448	X2(K) =	-0.82170
K=	145	Y2(K) =	5.61175	X2(K) =	-0.82160
K=	146	Y2(K) =	5.60912	X2(K) =	-0.82150
K=	147	Y2(K) =	5.60660	X2(K) =	-0.82139
K=	148	Y2(K) =	5.60419	X2(K) =	-0.82127
K=	149	Y2(K) =	5.60189	X2(K) =	-0.82115
K=	150	Y2(K) =	5.59969	X2(K) =	-0.82103
K=	151	Y2(K) =	5.59760	X2(K) =	-0.82090
K=	152	Y2(K) =	5.59562	X2(K) =	-0.82077
K=	153	Y2(K) =	5.59500	X2(K) =	-0.82058
K=	154	Y2(K) =	5.59400	X2(K) =	-0.82027
K=	155	Y2(K) =	5.59300	X2(K) =	-0.81997
K=	156	Y2(K) =	5.59200	X2(K) =	-0.81967
K=	157	Y2(K) =	5.59100	X2(K) =	-0.81937
K=	158	Y2(K) =	5.59000	X2(K) =	-0.81908
K=	159	Y2(K) =	5.58900	X2(K) =	-0.81879
K=	160	Y2(K) =	5.58800	X2(K) =	-0.81851
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K=	163	Y2(K) =	5.58500	X2(K) =	-0.81767
K=	164	Y2(K) =	5.58400	X2(K) =	-0.81740
K=	165	Y2(K) =	5.58300	X2(K) =	-0.81714
K=	166	Y2(K) =	5.58200	X2(K) =	-0.81687
K=	167	Y2(K) =	5.58100	X2(K) =	-0.81662
K=	168	Y2(K) =	5.58000	X2(K) =	-0.81636
K=	169	Y2(K) =	5.57900	X2(K) =	-0.81611
K=	170	Y2(K) =	5.57800	X2(K) =	-0.81586
K=	171	Y2(K) =	5.57700	X2(K) =	-0.81562
K=	172	Y2(K) =	5.57600	X2(K) =	-0.81538
K=	173	Y2(K) =	5.57500	X2(K) =	-0.81514
K=	174	Y2(K) =	5.57400	X2(K) =	-0.81491
K=	175	Y2(K) =	5.57300	X2(K) =	-0.81468
K=	176	Y2(K) =	5.57200	X2(K) =	-0.81445
K=	177	Y2(K) =	5.57100	X2(K) =	-0.81377
K=	178	Y2(K) =	5.57000	X2(K) =	-0.81347
K=	179	Y2(K) =	5.56900	X2(K) =	-0.81317
K=	180	Y2(K) =	5.56800	X2(K) =	-0.81288
K=	181	Y2(K) =	5.56700	X2(K) =	-0.81259
K=	182	Y2(K) =	5.56600	X2(K) =	-0.81231
K=	183	Y2(K) =	5.56500	X2(K) =	-0.81203
K=	184	Y2(K) =	5.56400	X2(K) =	-0.81175
K=	185	Y2(K) =	5.56300	X2(K) =	-0.81147
K=	186	Y2(K) =	5.56200	X2(K) =	-0.81120
K=	187	Y2(K) =	5.56100	X2(K) =	-0.81094
K=	188	Y2(K) =	5.56000	X2(K) =	-0.81068
K=	189	Y2(K) =	5.55900	X2(K) =	-0.81042
K=	190	Y2(K) =	5.55800	X2(K) =	-0.81016
K=	191	Y2(K) =	5.55700	X2(K) =	-0.80991
K=	192	Y2(K) =	5.55600	X2(K) =	-0.80966
K=	193	Y2(K) =	5.55500	X2(K) =	-0.80942
K=	194	Y2(K) =	5.55400	X2(K) =	-0.80918

K= 195	Y2(K) =	5.55300	X2(K) = -0.80894
K= 196	Y2(K) =	5.55200	X2(K) = -0.80871
K= 197	Y2(K) =	5.55100	X2(K) = -0.80848
K= 198	Y2(K) =	5.55000	X2(K) = -0.80825
K= 199	Y2(K) =	5.54900	X2(K) = -0.80803
K= 200	Y2(K) =	5.54800	X2(K) = -0.80781
K= 201	Y2(K) =	5.54700	X2(K) = -0.80734
K= 202	Y2(K) =	5.54600	X2(K) = -0.80705
K= 203	Y2(K) =	5.54500	X2(K) = -0.80677
K= 204	Y2(K) =	5.54400	X2(K) = -0.80648
K= 205	Y2(K) =	5.54300	X2(K) = -0.80620
K= 206	Y2(K) =	5.54200	X2(K) = -0.80593
K= 207	Y2(K) =	5.54100	X2(K) = -0.80565
K= 208	Y2(K) =	5.54000	X2(K) = -0.80539
K= 209	Y2(K) =	5.53900	X2(K) = -0.80512
K= 210	Y2(K) =	5.53800	X2(K) = -0.80486
K= 211	Y2(K) =	5.53700	X2(K) = -0.80460
K= 212	Y2(K) =	5.53600	X2(K) = -0.80435
K= 213	Y2(K) =	5.53500	X2(K) = -0.80410
K= 214	Y2(K) =	5.53400	X2(K) = -0.80385
K= 215	Y2(K) =	5.53300	X2(K) = -0.80361
K= 216	Y2(K) =	5.53200	X2(K) = -0.80337
K= 217	Y2(K) =	5.53100	X2(K) = -0.80314
K= 218	Y2(K) =	5.53000	X2(K) = -0.80290
K= 219	Y2(K) =	5.52900	X2(K) = -0.80268
K= 220	Y2(K) =	5.52800	X2(K) = -0.80245
K= 221	Y2(K) =	5.52700	X2(K) = -0.80223
K= 222	Y2(K) =	5.52600	X2(K) = -0.80201
K= 223	Y2(K) =	5.52500	X2(K) = -0.80180
K= 224	Y2(K) =	5.52400	X2(K) = -0.80159
K= 225	Y2(K) =	5.52300	X2(K) = -0.80131
K= 226	Y2(K) =	5.52200	X2(K) = -0.80103
K= 227	Y2(K) =	5.52100	X2(K) = -0.80075
K= 228	Y2(K) =	5.52000	X2(K) = -0.80048
K= 229	Y2(K) =	5.51900	X2(K) = -0.80021
K= 230	Y2(K) =	5.51800	X2(K) = -0.79994
K= 231	Y2(K) =	5.51700	X2(K) = -0.79968
K= 232	Y2(K) =	5.51600	X2(K) = -0.79942
K= 233	Y2(K) =	5.51500	X2(K) = -0.79917
K= 234	Y2(K) =	5.51400	X2(K) = -0.79892
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K= 237	Y2(K) =	5.51100	X2(K) = -0.79810
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K= 240	Y2(K) =	5.50800	X2(K) = -0.79749
K= 241	Y2(K) =	5.50700	X2(K) = -0.79726
K= 242	Y2(K) =	5.50600	X2(K) = -0.79704
K= 243	Y2(K) =	5.50500	X2(K) = -0.79682
K= 244	Y2(K) =	5.50400	X2(K) = -0.79660
K= 245	Y2(K) =	5.50300	X2(K) = -0.79639
K= 246	Y2(K) =	5.50200	X2(K) = -0.79619
K= 247	Y2(K) =	5.50100	X2(K) = -0.79598
K= 248	Y2(K) =	5.50000	X2(K) = -0.79578
K= 249	Y2(K) =	5.49900	X2(K) = -0.79558
K= 250	Y2(K) =	5.49800	X2(K) = -0.79539
K= 251	Y2(K) =	5.49700	X2(K) = -0.79513
K= 252	Y2(K) =	5.49600	X2(K) = -0.79487
K= 253	Y2(K) =	5.49500	X2(K) = -0.79461
K= 254	Y2(K) =	5.49400	X2(K) = -0.79435
K= 255	Y2(K) =	5.49300	X2(K) = -0.79410
K= 256	Y2(K) =	5.49200	X2(K) = -0.79385
K= 257	Y2(K) =	5.49100	X2(K) = -0.79361
K= 258	Y2(K) =	5.49000	X2(K) = -0.79337
K= 259	Y2(K) =	5.48900	X2(K) = -0.79313
K= 260	Y2(K) =	5.48800	X2(K) = -0.79290

K= 261	Y2(K) =	5.48700	X2(K) =	-0.79267
K= 262	Y2(K) =	5.48600	X2(K) =	-0.79245
K= 263	Y2(K) =	5.48500	X2(K) =	-0.79222
K= 264	Y2(K) =	5.48400	X2(K) =	-0.79201
K= 265	Y2(K) =	5.48300	X2(K) =	-0.79179
K= 266	Y2(K) =	5.48200	X2(K) =	-0.79158
K= 267	Y2(K) =	5.48100	X2(K) =	-0.79137
K= 268	Y2(K) =	5.48000	X2(K) =	-0.79117
K= 269	Y2(K) =	5.47900	X2(K) =	-0.79097
K= 270	Y2(K) =	5.47800	X2(K) =	-0.79077
K= 271	Y2(K) =	5.47700	X2(K) =	-0.79058
K= 272	Y2(K) =	5.47600	X2(K) =	-0.79039
K= 273	Y2(K) =	5.47500	X2(K) =	-0.79020
K= 274	Y2(K) =	5.47400	X2(K) =	-0.79002
K= 275	Y2(K) =	5.47300	X2(K) =	-0.78984
K= 276	Y2(K) =	5.47200	X2(K) =	-0.78965
K= 277	Y2(K) =	5.47100	X2(K) =	-0.78940
K= 278	Y2(K) =	5.47000	X2(K) =	-0.78916
K= 279	Y2(K) =	5.[illegible]900	X2(K) =	-0.78892
K= 280	Y2(K) =	5.46800	X2(K) =	-0.78869
K= 281	Y2(K) =	5.46700	X2(K) =	-0.78846
K= 282	Y2(K) =	5.46600	X2(K) =	-0.78823
K= 283	Y2(K) =	5.46500	X2(K) =	-0.78800
K= 284	Y2(K) =	5.46400	X2(K) =	-0.78778
K= 285	Y2(K) =	5.46300	X2(K) =	-0.78757
K= 286	Y2(K) =	5.46200	X2(K) =	-0.78735
K= 287	Y2(K) =	5.46100	X2(K) =	-0.78714
K= 288	Y2(K) =	5.46000	X2(K) =	-0.78694
K= 289	Y2(K) =	5.45900	X2(K) =	-0.78673
K= 290	Y2(K) =	5.45800	X2(K) =	-0.78653
K= 291	Y2(K) =	5.45700	X2(K) =	-0.78634
K= 292	Y2(K) =	5.45600	X2(K) =	-0.78615
K= 293	Y2(K) =	5.45500	X2(K) =	-0.78596
K= 294	Y2(K) =	5.45400	X2(K) =	-0.78577
K= 295	Y2(K) =	5.45300	X2(K) =	-0.78559
K= 296	Y2(K) =	5.45200	X2(K) =	-0.78541
K= 297	Y2(K) =	5.45100	X2(K) =	-0.78524
K= 298	Y2(K) =	5.45000	X2(K) =	-0.78507
K= 299	Y2(K) =	5.44900	X2(K) =	-0.78490
K= 300	Y2(K) =	5.44800	X2(K) =	-0.78473
K= 301	Y2(K) =	5.44700	X2(K) =	-0.78457
K= 302	Y2(K) =	5.44600	X2(K) =	-0.78438
K= 303	Y2(K) =	5.44500	X2(K) =	-0.78415
K= 304	Y2(K) =	5.44400	X2(K) =	-0.78393
K= 305	Y2(K) =	5.44300	X2(K) =	-0.78371
K= 306	Y2(K) =	5.44200	X2(K) =	-0.78350
K= 307	Y2(K) =	5.44100	X2(K) =	-0.78328
K= 308	Y2(K) =	5.44000	X2(K) =	-0.78308
K= 309	Y2(K) =	5.43900	X2(K) =	-0.78287
K= 310	Y2(K) =	5.43800	X2(K) =	-0.78267
K= 311	Y2(K) =	5.43700	X2(K) =	-0.78248
K= 312	Y2(K) =	5.43600	X2(K) =	-0.78228
K= 313	Y2(K) =	5.43500	X2(K) =	-0.78209
K= 314	Y2(K) =	5.43400	X2(K) =	-0.78191
K= 315	Y2(K) =	5.43300	X2(K) =	-0.78172
K= 316	Y2(K) =	5.43200	X2(K) =	-0.78154
K= 317	Y2(K) =	5.43100	X2(K) =	-0.78137
K= 318	Y2(K) =	5.43000	X2(K) =	-0.78120
K= 319	Y2(K) =	5.42900	X2(K) =	-0.78103
K= 320	Y2(K) =	5.42800	X2(K) =	-0.78086
K= 321	Y2(K) =	5.42700	X2(K) =	-0.78070
K= 322	Y2(K) =	5.42600	X2(K) =	-0.78054
K= 323	Y2(K) =	5.42500	X2(K) =	-0.78039
K= 324	Y2(K) =	5.42400	X2(K) =	-0.78023
K= 325	Y2(K) =	5.42300	X2(K) =	-0.78009
K= 326	Y2(K) =	5.42200	X2(K) =	-0.77994

K=	327	Y2(K) =	5.42100	X2(K) =	-0.77979
K=	328	Y2(K) =	5.42000	X2(K) =	-0.77958
K=	329	Y2(K) =	5.41900	X2(K) =	-0.77938
K=	330	Y2(K) =	5.41800	X2(K) =	-0.77918
K=	331	Y2(K) =	5.41700	X2(K) =	-0.77898
K=	332	Y2(K) =	5.41600	X2(K) =	-0.77879
K=	333	Y2(K) =	5.41500	X2(K) =	-0.77860
K=	334	Y2(K) =	5.41400	X2(K) =	-0.77841
K=	335	Y2(K) =	5.41300	X2(K) =	-0.77823
K=	336	Y2(K) =	5.41200	X2(K) =	-0.77805
K=	337	Y2(K) =	5.41100	X2(K) =	-0.77787
K=	338	Y2(K) =	5.41000	X2(K) =	-0.77770
K=	339	Y2(K) =	5.40900	X2(K) =	-0.77753
K=	340	Y2(K) =	5.40800	X2(K) =	-0.77737
K=	341	Y2(K) =	5.40700	X2(K) =	-0.77720
K=	342	Y2(K) =	5.40600	X2(K) =	-0.77705
K=	343	Y2(K) =	5.40500	X2(K) =	-0.77689
K=	344	Y2(K) =	5.40400	X2(K) =	-0.77674
K=	345	Y2(K) =	5.40300	X2(K) =	-0.77659
K=	346	Y2(K) =	5.40200	X2(K) =	-0.77645
K=	347	Y2(K) =	5.40100	X2(K) =	-0.77631
K=	348	Y2(K) =	5.40000	X2(K) =	-0.77617
K=	349	Y2(K) =	5.39900	X2(K) =	-0.77603
K=	350	Y2(K) =	5.39800	X2(K) =	-0.77590
K=	351	Y2(K) =	5.39700	X2(K) =	-0.77578
K=	352	Y2(K) =	5.39600	X2(K) =	-0.77565
K=	353	Y2(K) =	5.39500	X2(K) =	-0.77546
K=	354	Y2(K) =	5.39400	X2(K) =	-0.77528
K=	355	Y2(K) =	5.39300	X2(K) =	-0.77509
K=	356	Y2(K) =	5.39200	X2(K) =	-0.77492
K=	357	Y2(K) =	5.39100	X2(K) =	-0.77474
K=	358	Y2(K) =	5.39000	X2(K) =	-0.77457
K=	359	Y2(K) =	5.38900	X2(K) =	-0.77440
K=	360	Y2(K) =	5.38800	X2(K) =	-0.77424
K=	361	Y2(K) =	5.38700	X2(K) =	-0.77408
K=	362	Y2(K) =	5.38600	X2(K) =	-0.77392
K=	363	Y2(K) =	5.38500	X2(K) =	-0.77377
K=	364	Y2(K) =	5.38400	X2(K) =	-0.77362
K=	365	Y2(K) =	5.38300	X2(K) =	-0.77347
K=	366	Y2(K) =	5.38200	X2(K) =	-0.77333
K=	367	Y2(K) =	5.38100	X2(K) =	-0.77319
K=	368	Y2(K) =	5.38000	X2(K) =	-0.77305
K=	369	Y2(K) =	5.37900	X2(K) =	-0.77292
K=	370	Y2(K) =	5.37800	X2(K) =	-0.77279
K=	371	Y2(K) =	5.37700	X2(K) =	-0.77267
K=	372	Y2(K) =	5.37600	X2(K) =	-0.77254
K=	373	Y2(K) =	5.37500	X2(K) =	-0.77242
K=	374	Y2(K) =	5.37400	X2(K) =	-0.77231
K=	375	Y2(K) =	5.37300	X2(K) =	-0.77220
K=	376	Y2(K) =	5.37200	X2(K) =	-0.77209
K=	377	Y2(K) =	5.37100	X2(K) =	-0.77197
K=	378	Y2(K) =	5.37000	X2(K) =	-0.77181
K=	379	Y2(K) =	5.36900	X2(K) =	-0.77164
K=	380	Y2(K) =	5.36800	X2(K) =	-0.77148
K=	381	Y2(K) =	5.36700	X2(K) =	-0.77132
K=	382	Y2(K) =	5.36600	X2(K) =	-0.77117
K=	383	Y2(K) =	5.36500	X2(K) =	-0.77102
K=	384	Y2(K) =	5.36400	X2(K) =	-0.77087
K=	385	Y2(K) =	5.36300	X2(K) =	-0.77072
K=	386	Y2(K) =	5.36200	X2(K) =	-0.77058
K=	387	Y2(K) =	5.36100	X2(K) =	-0.77045
K=	388	Y2(K) =	5.36000	X2(K) =	-0.77031
K=	389	Y2(K) =	5.35900	X2(K) =	-0.77018
K=	390	Y2(K) =	5.35800	X2(K) =	-0.77006
K=	391	Y2(K) =	5.35700	X2(K) =	-0.76993
K=	392	Y2(K) =	5.35600	X2(K) =	-0.76981

K= 393	Y2(K) = 5.35500	X2(K) = -0.76970
K= 394	Y2(K) = 5.35400	X2(K) = -0.76958
K= 395	Y2(K) = 5.35300	X2(K) = -0.76947
K= 396	Y2(K) = 5.35200	X2(K) = -0.76937
K= 397	Y2(K) = 5.35100	X2(K) = -0.76926
K= 398	Y2(K) = 5.35000	X2(K) = -0.76916
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K= 400	Y2(K) = 5.34800	X2(K) = -0.76897
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K= 408	Y2(K) = 5.34000	X2(K) = -0.76794
K= 409	Y2(K) = 5.33900	X2(K) = -0.76781
K= 410	Y2(K) = 5.33800	X2(K) = -0.76769
K= 411	Y2(K) = 5.33700	X2(K) = -0.76757
K= 412	Y2(K) = 5.33600	X2(K) = -0.76746
K= 413	Y2(K) = 5.33500	X2(K) = -0.76734
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K= 415	Y2(K) = 5.33300	X2(K) = -0.76713
K= 416	Y2(K) = 5.33200	X2(K) = -0.76702
K= 417	Y2(K) = 5.33100	X2(K) = -0.76693
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K= 419	Y2(K) = 5.32900	X2(K) = -0.76674
K= 420	Y2(K) = 5.32800	X2(K) = -0.76665
K= 421	Y2(K) = 5.32700	X2(K) = -0.76656
K= 422	Y2(K) = 5.32600	X2(K) = -0.76648
K= 423	Y2(K) = 5.32500	X2(K) = -0.76640
K= 424	Y2(K) = 5.32400	X2(K) = -0.76632
K= 425	Y2(K) = 5.32300	X2(K) = -0.76625
K= 426	Y2(K) = 5.32200	X2(K) = -0.76618
K= 427	Y2(K) = 5.32100	X2(K) = -0.76606
K= 428	Y2(K) = 5.32000	X2(K) = -0.76594
K= 429	Y2(K) = 5.31900	X2(K) = -0.76581
K= 430	Y2(K) = 5.31800	X2(K) = -0.76570
K= 431	Y2(K) = 5.31700	X2(K) = -0.76558
K= 432	Y2(K) = 5.31600	X2(K) = -0.76547
K= 433	Y2(K) = 5.31500	X2(K) = -0.76536
K= 434	Y2(K) = 5.31400	X2(K) = -0.76526
K= 435	Y2(K) = 5.31300	X2(K) = -0.76516
K= 436	Y2(K) = 5.31200	X2(K) = -0.76506
K= 437	Y2(K) = 5.31100	X2(K) = -0.76497
K= 438	Y2(K) = 5.31000	X2(K) = -0.76487
K= 439	Y2(K) = 5.30900	X2(K) = -0.76479
K= 440	Y2(K) = 5.30800	X2(K) = -0.76470
K= 441	Y2(K) = 5.30700	X2(K) = -0.76462
K= 442	Y2(K) = 5.30600	X2(K) = -0.76454
K= 443	Y2(K) = 5.30500	X2(K) = -0.76447
K= 444	Y2(K) = 5.30400	X2(K) = -0.76440
K= 445	Y2(K) = 5.30300	X2(K) = -0.76433
K= 446	Y2(K) = 5.30200	X2(K) = -0.76427
K= 447	Y2(K) = 5.30100	X2(K) = -0.76421
K= 448	Y2(K) = 5.30000	X2(K) = -0.76415
K= 449	Y2(K) = 5.29900	X2(K) = -0.76410
K= 450	Y2(K) = 5.29800	X2(K) = -0.76405
K= 451	Y2(K) = 5.29700	X2(K) = -0.76396
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K= 453	Y2(K) = 5.29500	X2(K) = -0.76375
K= 454	Y2(K) = 5.29400	X2(K) = -0.76365
K= 455	Y2(K) = 5.29300	X2(K) = -0.76356
K= 456	Y2(K) = 5.29200	X2(K) = -0.76347
K= 457	Y2(K) = 5.29100	X2(K) = -0.76339
K= 458	Y2(K) = 5.29000	X2(K) = -0.76330

K= 459	Y2(K) =	5.28900	X2(K) = -0.76322
K= 460	Y2(K) =	5.28800	X2(K) = -0.76314
K= 461	Y2(K) =	5.28700	X2(K) = -0.76306
K= 462	Y2(K) =	5.28600	X2(K) = -0.76299
K= 463	Y2(K) =	5.28500	X2(K) = -0.76292
K= 464	Y2(K) =	5.28400	X2(K) = -0.76286
K= 465	Y2(K) =	5.28300	X2(K) = -0.76280
K= 466	Y2(K) =	5.28200	X2(K) = -0.76274
K= 467	Y2(K) =	5.28100	X2(K) = -0.76269
K= 468	Y2(K) =	5.28000	X2(K) = -0.76264
K= 469	Y2(K) =	5.27900	X2(K) = -0.76259
K= 470	Y2(K) =	5.27800	X2(K) = -0.76254
K= 471	Y2(K) =	5.27700	X2(K) = -0.76250
K= 472	Y2(K) =	5.27600	X2(K) = -0.76246
K= 473	Y2(K) =	5.27500	X2(K) = -0.76243
K= 474	Y2(K) =	5.27400	X2(K) = -0.76240
K= 475	Y2(K) =	5.27300	X2(K) = -0.76234
K= 476	Y2(K) =	5.27200	X2(K) = -0.76225
K= 477	Y2(K) =	5.27100	X2(K) = -0.76217
K= 478	Y2(K) =	5.27000	X2(K) = -0.76210
K= 479	Y2(K) =	5.26900	X2(K) = -0.76202
K= 480	Y2(K) =	5.26800	X2(K) = -0.76195
K= 481	Y2(K) =	5.26700	X2(K) = -0.76188
K= 482	Y2(K) =	5.26600	X2(K) = -0.76182
K= 483	Y2(K) =	5.26500	X2(K) = -0.76176
K= 484	Y2(K) =	5.26400	X2(K) = -0.76170
K= 485	Y2(K) =	5.26300	X2(K) = -0.76165
K= 486	Y2(K) =	5.26200	X2(K) = -0.76160
K= 487	Y2(K) =	5.26100	X2(K) = -0.76155
K= 488	Y2(K) =	5.26000	X2(K) = -0.76151
K= 489	Y2(K) =	5.25900	X2(K) = -0.76147
K= 490	Y2(K) =	5.25800	X2(K) = -0.76143
K= 491	Y2(K) =	5.25700	X2(K) = -0.76140
K= 492	Y2(K) =	5.25600	X2(K) = -0.76137
K= 493	Y2(K) =	5.25500	X2(K) = -0.76134
K= 494	Y2(K) =	5.25400	X2(K) = -0.76132
K= 495	Y2(K) =	5.25300	X2(K) = -0.76130
K= 496	Y2(K) =	5.25200	X2(K) = -0.76128
K= 497	Y2(K) =	5.25100	X2(K) = -0.76127
K= 498	Y2(K) =	5.25000	X2(K) = -0.76126
K= 499	Y2(K) =	5.24900	X2(K) = -0.76121
K= 500	Y2(K) =	5.24800	X2(K) = -0.76115
K= 501	Y2(K) =	5.24700	X2(K) = -0.76109
K= 502	Y2(K) =	5.24600	X2(K) = -0.76103
K= 503	Y2(K) =	5.24500	X2(K) = -0.76098
K= 504	Y2(K) =	5.24400	X2(K) = -0.76093
K= 505	Y2(K) =	5.24300	X2(K) = -0.76089
K= 506	Y2(K) =	5.24200	X2(K) = -0.76085
K= 507	Y2(K) =	5.24100	X2(K) = -0.76081
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K= 509	Y2(K) =	5.23900	X2(K) = -0.76074
K= 510	Y2(K) =	5.23800	X2(K) = -0.76072
K= 511	Y2(K) =	5.23700	X2(K) = -0.76069
K= 512	Y2(K) =	5.23600	X2(K) = -0.76067
K= 513	Y2(K) =	5.23500	X2(K) = -0.76065
K= 514	Y2(K) =	5.23400	X2(K) = -0.76064
K= 515	Y2(K) =	5.23300	X2(K) = -0.76063
K= 516	Y2(K) =	5.23200	X2(K) = -0.76062
K= 517	Y2(K) =	5.23100	X2(K) = -0.76061
K= 518	Y2(K) =	5.23000	X2(K) = -0.76061
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K= 524	Y2(K) =	5.22400	X2(K) = -0.76055

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K=	527	Y2(K) =	5.22100		X2(K) =	-0.76046	
K=	528	Y2(K) =	5.22000		X2(K) =	-0.76043	
K=	529	Y2(K) =	5.21900		X2(K) =	-0.76041	
K=	530	Y2(K) =	5.21800		X2(K) =	-0.76040	
K=	531	Y2(K) =	5.21700		X2(K) =	-0.76038	
K=	532	Y2(K) =	5.21600		X2(K) =	-0.76037	
K=	533	Y2(K) =	5.21500		X2(K) =	-0.76036	
K=	534	Y2(K) =	5.21400		X2(K) =	-0.76036	
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K=	536	Y2(K) =	5.21200		X2(K) =	-0.76036	
K=	537	Y2(K) =	5.21100		X2(K) =	-0.76036	
K=	538	Y2(K) =	5.21000		X2(K) =	-0.76037	
K=	539	Y2(K) =	5.20900		X2(K) =	-0.76038	
K=	540	Y2(K) =	5.20800		X2(K) =	-0.76040	
K=	541	Y2(K) =	5.20700		X2(K) =	-0.76042	
K=	542	Y2(K) =	5.20600		X2(K) =	-0.76044	
K=	543	Y2(K) =	5.20500		X2(K) =	-0.76046	
K=	544	Y2(K) =	5.20400		X2(K) =	-0.76049	
K=	545	Y2(K) =	5.20300		X2(K) =	-0.76052	
K=	546	Y2(K) =	5.20200		X2(K) =	-0.76052	
K=	547	Y2(K) =	5.20100		X2(K) =	-0.76051	
K=	548	Y2(K) =	5.20000		X2(K) =	-0.76049	
K=	549	Y2(K) =	5.19900		X2(K) =	-0.76048	
K=	550	Y2(K) =	5.19800		X2(K) =	-0.76048	
K=	551	Y2(K) =	5.19700		X2(K) =	-0.76047	
K=	552	Y2(K) =	5.19600		X2(K) =	-0.76047	
K=	553	Y2(K) =	5.19500		X2(K) =	-0.76048	
K=	554	Y2(K) =	5.19400		X2(K) =	-0.76048	
K=	555	Y2(K) =	5.19300		X2(K) =	-0.76049	
K=	556	Y2(K) =	5.19200		X2(K) =	-0.76051	
K=	557	Y2(K) =	5.19100		X2(K) =	-0.76052	
K=	558	Y2(K) =	5.19000		X2(K) =	-0.76054	
K=	559	Y2(K) =	5.18900		X2(K) =	-0.76057	
K=	560	Y2(K) =	5.18800		X2(K) =	-0.76059	
K=	561	Y2(K) =	5.18700		X2(K) =	-0.76062	
K=	562	Y2(K) =	5.18600		X2(K) =	-0.76066	
K=	563	Y2(K) =	5.18500		X2(K) =	-0.76069	
K=	564	Y2(K) =	5.18400		X2(K) =	-0.76073	
K=	565	Y2(K) =	5.18300		X2(K) =	-0.76078	
K=	566	Y2(K) =	5.18200		X2(K) =	-0.76082	
K=	567	Y2(K) =	5.18100		X2(K) =	-0.76087	
K=	568	Y2(K) =	5.18000		X2(K) =	-0.76093	
K=	569	Y2(K) =	5.17900		X2(K) =	-0.76096	
K=	570	Y2(K) =	5.17800		X2(K) =	-0.76097	
K=	571	Y2(K) =	5.17700		X2(K) =	-0.76098	
K=	572	Y2(K) =	5.17600		X2(K) =	-0.76099	
K=	573	Y2(K) =	5.17500		X2(K) =	-0.76100	
K=	574	Y2(K) =	5.17400		X2(K) =	-0.76102	
K=	575	Y2(K) =	5.17300		X2(K) =	-0.76105	
K=	576	Y2(K) =	5.17200		X2(K) =	-0.76107	
K=	577	Y2(K) =	5.17100		X2(K) =	-0.76110	
K=	578	Y2(K) =	5.17000		X2(K) =	-0.76114	
K=	579	Y2(K) =	5.16900		X2(K) =	-0.76117	
K=	580	Y2(K) =	5.16800		X2(K) =	-0.76121	
K=	581	Y2(K) =	5.16700		X2(K) =	-0.76125	
K=	582	Y2(K) =	5.16600		X2(K) =	-0.76130	
K=	583	Y2(K) =	5.16500		X2(K) =	-0.76135	
K=	584	Y2(K) =	5.16400		X2(K) =	-0.76140	
K=	585	Y2(K) =	5.16300		X2(K) =	-0.76146	
K=	586	Y2(K) =	5.16200		X2(K) =	-0.76152	
K=	587	Y2(K) =	5.16100		X2(K) =	-0.76158	
K=	588	Y2(K) =	5.16000		X2(K) =	-0.76165	
K=	589	Y2(K) =	5.15900		X2(K) =	-0.76172	
K=	590	Y2(K) =	5.15800		X2(K) =	-0.76177	

K= 591	Y2(K) =	5.15700	X2(K) =	-0.76187
K= 592	Y2(K) =	5.15600	X2(K) =	-0.76192
K= 593	Y2(K) =	5.15500	X2(K) =	-0.76195
K= 594	Y2(K) =	5.15400	X2(K) =	-0.76199
K= 595	Y2(K) =	5.15300	X2(K) =	-0.76202
K= 596	Y2(K) =	5.15200	X2(K) =	-0.76206
K= 597	Y2(K) =	5.15100	X2(K) =	-0.76211
K= 598	Y2(K) =	5.15000	X2(K) =	-0.76216
K= 599	Y2(K) =	5.14900	X2(K) =	-0.76221
K= 600	Y2(K) =	5.14800	X2(K) =	-0.76226
K= 601	Y2(K) =	5.14700	X2(K) =	-0.76232
K= 602	Y2(K) =	5.14600	X2(K) =	-0.76238
K= 603	Y2(K) =	5.14500	X2(K) =	-0.76244
K= 604	Y2(K) =	5.14400	X2(K) =	-0.76251
K= 605	Y2(K) =	5.14300	X2(K) =	-0.76258
K= 606	Y2(K) =	5.14200	X2(K) =	-0.76265
K= 607	Y2(K) =	5.14100	X2(K) =	-0.76273
K= 608	Y2(K) =	5.14000	X2(K) =	-0.76281
K= 609	Y2(K) =	5.13900	X2(K) =	-0.76289
K= 610	Y2(K) =	5.13800	X2(K) =	-0.76298
K= 611	Y2(K) =	5.13700	X2(K) =	-0.76307
K= 612	Y2(K) =	5.13600	X2(K) =	-0.76316
K= 613	Y2(K) =	5.13500	X2(K) =	-0.76326
K= 614	Y2(K) =	5.13400	X2(K) =	-0.76336
K= 615	Y2(K) =	5.13300	X2(K) =	-0.76344
K= 616	Y2(K) =	5.13200	X2(K) =	-0.76349
K= 617	Y2(K) =	5.13100	X2(K) =	-0.76355
K= 618	Y2(K) =	5.13000	X2(K) =	-0.76361
K= 619	Y2(K) =	5.12900	X2(K) =	-0.76368
K= 620	Y2(K) =	5.12800	X2(K) =	-0.76375
K= 621	Y2(K) =	5.12700	X2(K) =	-0.76382
K= 622	Y2(K) =	5.12600	X2(K) =	-0.76390
K= 623	Y2(K) =	5.12500	X2(K) =	-0.76397
K= 624	Y2(K) =	5.12400	X2(K) =	-0.76406
K= 625	Y2(K) =	5.12300	X2(K) =	-0.76414
K= 626	Y2(K) =	5.12200	X2(K) =	-0.76423
K= 627	Y2(K) =	5.12100	X2(K) =	-0.76432
K= 628	Y2(K) =	5.12000	X2(K) =	-0.76442
K= 629	Y2(K) =	5.11900	X2(K) =	-0.76452
K= 630	Y2(K) =	5.11800	X2(K) =	-0.76462
K= 631	Y2(K) =	5.11700	X2(K) =	-0.76473
K= 632	Y2(K) =	5.11600	X2(K) =	-0.76484
K= 633	Y2(K) =	5.11500	X2(K) =	-0.76495
K= 634	Y2(K) =	5.11400	X2(K) =	-0.76507
K= 635	Y2(K) =	5.11300	X2(K) =	-0.76519
K= 636	Y2(K) =	5.11200	X2(K) =	-0.76531
K= 637	Y2(K) =	5.11100	X2(K) =	-0.76544
K= 638	Y2(K) =	5.11000	X2(K) =	-0.76552
K= 639	Y2(K) =	5.10900	X2(K) =	-0.76560
K= 640	Y2(K) =	5.10800	X2(K) =	-0.76569
K= 641	Y2(K) =	5.10700	X2(K) =	-0.76578
K= 642	Y2(K) =	5.10600	X2(K) =	-0.76587
K= 643	Y2(K) =	5.10500	X2(K) =	-0.76597
K= 644	Y2(K) =	5.10400	X2(K) =	-0.76607
K= 645	Y2(K) =	5.10300	X2(K) =	-0.76617
K= 646	Y2(K) =	5.10200	X2(K) =	-0.76628
K= 647	Y2(K) =	5.10100	X2(K) =	-0.76639
K= 648	Y2(K) =	5.10000	X2(K) =	-0.76650
K= 649	Y2(K) =	5.09900	X2(K) =	-0.76662
K= 650	Y2(K) =	5.09800	X2(K) =	-0.76674
K= 651	Y2(K) =	5.09700	X2(K) =	-0.76686
K= 652	Y2(K) =	5.09600	X2(K) =	-0.76699
K= 653	Y2(K) =	5.09500	X2(K) =	-0.76712
K= 654	Y2(K) =	5.09400	X2(K) =	-0.76725
K= 655	Y2(K) =	5.09300	X2(K) =	-0.76739
K= 656	Y2(K) =	5.09200	X2(K) =	-0.76753

K= 657	Y2(K) =	5.09100	X2(K) =	-0.76767
K= 658	Y2(K) =	5.09000	X2(K) =	-0.76782
K= 659	Y2(K) =	5.08900	X2(K) =	-0.76797
K= 660	Y2(K) =	5.08800	X2(K) =	-0.76810
K= 661	Y2(K) =	5.08700	X2(K) =	-0.76821
K= 662	Y2(K) =	5.08600	X2(K) =	-0.76832
K= 663	Y2(K) =	5.08500	X2(K) =	-0.76844
K= 664	Y2(K) =	5.08400	X2(K) =	-0.76855
K= 665	Y2(K) =	5.08300	X2(K) =	-0.76867
K= 666	Y2(K) =	5.08200	X2(K) =	-0.76880
K= 667	Y2(K) =	5.08100	X2(K) =	-0.76893
K= 668	Y2(K) =	5.08000	X2(K) =	-0.76906
K= 669	Y2(K) =	5.07900	X2(K) =	-0.76919
K= 670	Y2(K) =	5.07800	X2(K) =	-0.76933
K= 671	Y2(K) =	5.07700	X2(K) =	-0.76948
K= 672	Y2(K) =	5.07600	X2(K) =	-0.76962
K= 673	Y2(K) =	5.07500	X2(K) =	-0.76977
K= 674	Y2(K) =	5.07400	X2(K) =	-0.76992
K= 675	Y2(K) =	5.07300	X2(K) =	-0.77008
K= 676	Y2(K) =	5.07200	X2(K) =	-0.77024
K= 677	Y2(K) =	5.07100	X2(K) =	-0.77040
K= 678	Y2(K) =	5.07000	X2(K) =	-0.77057
K= 679	Y2(K) =	5.06900	X2(K) =	-0.77074
K= 680	Y2(K) =	5.06800	X2(K) =	-0.77091
K= 681	Y2(K) =	5.06700	X2(K) =	-0.77109
K= 682	Y2(K) =	5.06600	X2(K) =	-0.77126
K= 683	Y2(K) =	5.06500	X2(K) =	-0.77139
K= 684	Y2(K) =	5.06400	X2(K) =	-0.77153
K= 685	Y2(K) =	5.06300	X2(K) =	-0.77167
K= 686	Y2(K) =	5.06200	X2(K) =	-0.77182
K= 687	Y2(K) =	5.06100	X2(K) =	-0.77197
K= 688	Y2(K) =	5.06000	X2(K) =	-0.77212
K= 689	Y2(K) =	5.05900	X2(K) =	-0.77227
K= 690	Y2(K) =	5.05800	X2(K) =	-0.77243
K= 691	Y2(K) =	5.05700	X2(K) =	-0.77259
K= 692	Y2(K) =	5.05600	X2(K) =	-0.77276
K= 693	Y2(K) =	5.05500	X2(K) =	-0.77293
K= 694	Y2(K) =	5.05400	X2(K) =	-0.77310
K= 695	Y2(K) =	5.05300	X2(K) =	-0.77328
K= 696	Y2(K) =	5.05200	X2(K) =	-0.77346
K= 697	Y2(K) =	5.05100	X2(K) =	-0.77364
K= 698	Y2(K) =	5.05000	X2(K) =	-0.77383
K= 699	Y2(K) =	5.04900	X2(K) =	-0.77402
K= 700	Y2(K) =	5.04800	X2(K) =	-0.77421
K= 701	Y2(K) =	5.04700	X2(K) =	-0.77441
K= 702	Y2(K) =	5.04600	X2(K) =	-0.77461
K= 703	Y2(K) =	5.04500	X2(K) =	-0.77481
K= 704	Y2(K) =	5.04400	X2(K) =	-0.77502
K= 705	Y2(K) =	5.04300	X2(K) =	-0.77518
K= 706	Y2(K) =	5.04200	X2(K) =	-0.77535
K= 707	Y2(K) =	5.04100	X2(K) =	-0.77552
K= 708	Y2(K) =	5.04000	X2(K) =	-0.77569
K= 709	Y2(K) =	5.03900	X2(K) =	-0.77587
K= 710	Y2(K) =	5.03800	X2(K) =	-0.77605
K= 711	Y2(K) =	5.03700	X2(K) =	-0.77624
K= 712	Y2(K) =	5.03600	X2(K) =	-0.77642
K= 713	Y2(K) =	5.03500	X2(K) =	-0.77662
K= 714	Y2(K) =	5.03400	X2(K) =	-0.77681
K= 715	Y2(K) =	5.03300	X2(K) =	-0.77701
K= 716	Y2(K) =	5.03200	X2(K) =	-0.77721
K= 717	Y2(K) =	5.03100	X2(K) =	-0.77742
K= 718	Y2(K) =	5.03000	X2(K) =	-0.77763
K= 719	Y2(K) =	5.02900	X2(K) =	-0.77784
K= 720	Y2(K) =	5.02800	X2(K) =	-0.77805
K= 721	Y2(K) =	5.02700	X2(K) =	-0.77827
K= 722	Y2(K) =	5.02600	X2(K) =	-0.77850

K=	723	Y2(K) =	5.02500	X2(K) =	-0.77872
K=	724	Y2(K) =	5.02400	X2(K) =	-0.77896
K=	725	Y2(K) =	5.02300	X2(K) =	-0.77919
K=	726	Y2(K) =	5.02200	X2(K) =	-0.77942
K=	727	Y2(K) =	5.02100	X2(K) =	-0.77962
K=	728	Y2(K) =	5.02000	X2(K) =	-0.77981
K=	729	Y2(K) =	5.01900	X2(K) =	-0.78002
K=	730	Y2(K) =	5.01800	X2(K) =	-0.78022
K=	731	Y2(K) =	5.01700	X2(K) =	-0.78043
K=	732	Y2(K) =	5.01600	X2(K) =	-0.78064
K=	733	Y2(K) =	5.01500	X2(K) =	-0.78086
K=	734	Y2(K) =	5.01400	X2(K) =	-0.78107
K=	735	Y2(K) =	5.01300	X2(K) =	-0.78130
K=	736	Y2(K) =	5.01200	X2(K) =	-0.78152
K=	737	Y2(K) =	5.01100	X2(K) =	-0.78175
K=	738	Y2(K) =	5.01000	X2(K) =	-0.78199
K=	739	Y2(K) =	5.00900	X2(K) =	-0.78222
K=	740	Y2(K) =	5.00800	X2(K) =	-0.78246
K=	741	Y2(K) =	5.00700	X2(K) =	-0.78271
K=	742	Y2(K) =	5.00600	X2(K) =	-0.78296
K=	743	Y2(K) =	5.00500	X2(K) =	-0.78321
K=	744	Y2(K) =	5.00400	X2(K) =	-0.78346
K=	745	Y2(K) =	5.00300	X2(K) =	-0.78372
K=	746	Y2(K) =	5.00200	X2(K) =	-0.78398
K=	747	Y2(K) =	5.00100	X2(K) =	-0.78425
K=	748	Y2(K) =	5.00000	X2(K) =	-0.78450
K=	749	Y2(K) =	4.99900	X2(K) =	-0.78473
K=	750	Y2(K) =	4.99800	X2(K) =	-0.78496
K=	751	Y2(K) =	4.99700	X2(K) =	-0.78519
K=	752	Y2(K) =	4.99600	X2(K) =	-0.78543
K=	753	Y2(K) =	4.99500	X2(K) =	-0.78567
K=	754	Y2(K) =	4.99400	X2(K) =	-0.78592
K=	755	Y2(K) =	4.99300	X2(K) =	-0.78617
K=	756	Y2(K) =	4.99200	X2(K) =	-0.78642
K=	757	Y2(K) =	4.99100	X2(K) =	-0.78667
K=	758	Y2(K) =	4.99000	X2(K) =	-0.78693
K=	759	Y2(K) =	4.98900	X2(K) =	-0.78720
K=	760	Y2(K) =	4.98800	X2(K) =	-0.78746
K=	761	Y2(K) =	4.98700	X2(K) =	-0.78773
K=	762	Y2(K) =	4.98600	X2(K) =	-0.78801
K=	763	Y2(K) =	4.98500	X2(K) =	-0.78829
K=	764	Y2(K) =	4.98400	X2(K) =	-0.78857
K=	765	Y2(K) =	4.98300	X2(K) =	-0.78885
K=	766	Y2(K) =	4.98200	X2(K) =	-0.78914
K=	767	Y2(K) =	4.98100	X2(K) =	-0.78943
K=	768	Y2(K) =	4.98000	X2(K) =	-0.78973
K=	769	Y2(K) =	4.97900	X2(K) =	-0.79003
K=	770	Y2(K) =	4.97800	X2(K) =	-0.79030
K=	771	Y2(K) =	4.97700	X2(K) =	-0.79056
K=	772	Y2(K) =	4.97600	X2(K) =	-0.79083
K=	773	Y2(K) =	4.97500	X2(K) =	-0.79110
K=	774	Y2(K) =	4.97400	X2(K) =	-0.79137
K=	775	Y2(K) =	4.97300	X2(K) =	-0.79165
K=	776	Y2(K) =	4.97200	X2(K) =	-0.79193
K=	777	Y2(K) =	4.97100	X2(K) =	-0.79221
K=	778	Y2(K) =	4.97000	X2(K) =	-0.79250
K=	779	Y2(K) =	4.96900	X2(K) =	-0.79279
K=	780	Y2(K) =	4.96800	X2(K) =	-0.79309
K=	781	Y2(K) =	4.96700	X2(K) =	-0.79339
K=	782	Y2(K) =	4.96600	X2(K) =	-0.79369
K=	783	Y2(K) =	4.96500	X2(K) =	-0.79400
K=	784	Y2(K) =	4.96400	X2(K) =	-0.79431
K=	785	Y2(K) =	4.96300	X2(K) =	-0.79462
K=	786	Y2(K) =	4.96200	X2(K) =	-0.79494
K=	787	Y2(K) =	4.96100	X2(K) =	-0.79526
K=	788	Y2(K) =	4.96000	X2(K) =	-0.79559

K= 789	Y2(K) = 4.95900	X2(K) = -0.79592
K= 790	Y2(K) = 4.95800	X2(K) = -0.79625
K= 791	Y2(K) = 4.95700	X2(K) = -0.79658
K= 792	Y2(K) = 4.95600	X2(K) = -0.79687
K= 793	Y2(K) = 4.95500	X2(K) = -0.79717
K= 794	Y2(K) = 4.95400	X2(K) = -0.79748
K= 795	Y2(K) = 4.95300	X2(K) = -0.79778
K= 796	Y2(K) = 4.95200	X2(K) = -0.79809
K= 797	Y2(K) = 4.95100	X2(K) = -0.79841
K= 798	Y2(K) = 4.95000	X2(K) = -0.79873
K= 799	Y2(K) = 4.94900	X2(K) = -0.79905
K= 800	Y2(K) = 4.94800	X2(K) = -0.79938
K= 801	Y2(K) = 4.94700	X2(K) = -0.79971
K= 802	Y2(K) = 4.94600	X2(K) = -0.80004
K= 803	Y2(K) = 4.94500	X2(K) = -0.80038
K= 804	Y2(K) = 4.94400	X2(K) = -0.80072
K= 805	Y2(K) = 4.94300	X2(K) = -0.80107
K= 806	Y2(K) = 4.94200	X2(K) = -0.80142
K= 807	Y2(K) = 4.94100	X2(K) = -0.80177
K= 808	Y2(K) = 4.94000	X2(K) = -0.80213
K= 809	Y2(K) = 4.93900	X2(K) = -0.80249
K= 810	Y2(K) = 4.93800	X2(K) = -0.80286
K= 811	Y2(K) = 4.93700	X2(K) = -0.80323
K= 812	Y2(K) = 4.93600	X2(K) = -0.80360
K= 813	Y2(K) = 4.93500	X2(K) = -0.80393
K= 814	Y2(K) = 4.93400	X2(K) = -0.80427
K= 815	Y2(K) = 4.93300	X2(K) = -0.80461
K= 816	Y2(K) = 4.93200	X2(K) = -0.80495
K= 817	Y2(K) = 4.93100	X2(K) = -0.80530
K= 818	Y2(K) = 4.93000	X2(K) = -0.80565
K= 819	Y2(K) = 4.92900	X2(K) = -0.80601
K= 820	Y2(K) = 4.92800	X2(K) = -0.80637
K= 821	Y2(K) = 4.92700	X2(K) = -0.80673
K= 822	Y2(K) = 4.92600	X2(K) = -0.80710
K= 823	Y2(K) = 4.92500	X2(K) = -0.80747
K= 824	Y2(K) = 4.92400	X2(K) = -0.80785
K= 825	Y2(K) = 4.92300	X2(K) = -0.80823
K= 826	Y2(K) = 4.92200	X2(K) = -0.80861
K= 827	Y2(K) = 4.92100	X2(K) = -0.80900
K= 828	Y2(K) = 4.92000	X2(K) = -0.80939
K= 829	Y2(K) = 4.91900	X2(K) = -0.80979
K= 830	Y2(K) = 4.91800	X2(K) = -0.81019
K= 831	Y2(K) = 4.91700	X2(K) = -0.81059
K= 832	Y2(K) = 4.91600	X2(K) = -0.81100
K= 833	Y2(K) = 4.91500	X2(K) = -0.81142
K= 834	Y2(K) = 4.91400	X2(K) = -0.81179
K= 835	Y2(K) = 4.91300	X2(K) = -0.81217
K= 836	Y2(K) = 4.91200	X2(K) = -0.81255
K= 837	Y2(K) = 4.91100	X2(K) = -0.81293
K= 838	Y2(K) = 4.91000	X2(K) = -0.81332
K= 839	Y2(K) = 4.90900	X2(K) = -0.81371
K= 840	Y2(K) = 4.90800	X2(K) = -0.81411
K= 841	Y2(K) = 4.90700	X2(K) = -0.81451
K= 842	Y2(K) = 4.90600	X2(K) = -0.81492
K= 843	Y2(K) = 4.90500	X2(K) = -0.81533
K= 844	Y2(K) = 4.90400	X2(K) = -0.81574
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K= 847	Y2(K) = 4.90100	X2(K) = -0.81700
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K= 849	Y2(K) = 4.89900	X2(K) = -0.81787
K= 850	Y2(K) = 4.89800	X2(K) = -0.81831
K= 851	Y2(K) = 4.89700	X2(K) = -0.81875
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K= 853	Y2(K) = 4.89500	X2(K) = -0.81965
K= 854	Y2(K) = 4.89400	X2(K) = -0.82011

K= 855	Y2(K) = 4.89300	X2(K) = -0.82052
K= 856	Y2(K) = 4.89200	X2(K) = -0.82094
K= 857	Y2(K) = 4.89100	X2(K) = -0.82137
K= 858	Y2(K) = 4.89000	X2(K) = -0.82180
K= 859	Y2(K) = 4.88900	X2(K) = -0.82223
K= 860	Y2(K) = 4.88800	X2(K) = -0.82266
K= 861	Y2(K) = 4.88700	X2(K) = -0.82311
K= 862	Y2(K) = 4.88600	X2(K) = -0.82355
K= 863	Y2(K) = 4.88500	X2(K) = -0.82400
K= 864	Y2(K) = 4.88400	X2(K) = -0.82445
K= 865	Y2(K) = 4.88300	X2(K) = -0.82491
K= 866	Y2(K) = 4.88200	X2(K) = -0.82538
K= 867	Y2(K) = 4.88100	X2(K) = -0.82584
K= 868	Y2(K) = 4.88000	X2(K) = -0.82632
K= 869	Y2(K) = 4.87900	X2(K) = -0.82679
K= 870	Y2(K) = 4.87800	X2(K) = -0.82727
K= 871	Y2(K) = 4.87700	X2(K) = -0.82776
K= 872	Y2(K) = 4.87600	X2(K) = -0.82825
K= 873	Y2(K) = 4.87500	X2(K) = -0.82874
K= 874	Y2(K) = 4.87400	X2(K) = -0.82924
K= 875	Y2(K) = 4.87300	X2(K) = -0.82973
K= 876	Y2(K) = 4.87200	X2(K) = -0.83020
K= 877	Y2(K) = 4.87100	X2(K) = -0.83066
K= 878	Y2(K) = 4.87000	X2(K) = -0.83114
K= 879	Y2(K) = 4.86900	X2(K) = -0.83161
K= 880	Y2(K) = 4.86800	X2(K) = -0.83209
K= 881	Y2(K) = 4.86700	X2(K) = -0.83258
K= 882	Y2(K) = 4.86600	X2(K) = -0.83307
K= 883	Y2(K) = 4.86500	X2(K) = -0.83356
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K= 885	Y2(K) = 4.86300	X2(K) = -0.83457
K= 886	Y2(K) = 4.86200	X2(K) = -0.83507
K= 887	Y2(K) = 4.86100	X2(K) = -0.83559
K= 888	Y2(K) = 4.86000	X2(K) = -0.83611
K= 889	Y2(K) = 4.85900	X2(K) = -0.83663
K= 890	Y2(K) = 4.85800	X2(K) = -0.83716
K= 891	Y2(K) = 4.85700	X2(K) = -0.83769
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K= 894	Y2(K) = 4.85400	X2(K) = -0.83932
K= 895	Y2(K) = 4.85300	X2(K) = -0.83987
K= 896	Y2(K) = 4.85200	X2(K) = -0.84039
K= 897	Y2(K) = 4.85100	X2(K) = -0.84090
K= 898	Y2(K) = 4.85000	X2(K) = -0.84142
K= 899	Y2(K) = 4.84900	X2(K) = -0.84195
K= 900	Y2(K) = 4.84800	X2(K) = -0.84248
K= 901	Y2(K) = 4.84700	X2(K) = -0.84301
K= 902	Y2(K) = 4.84600	X2(K) = -0.84355
K= 903	Y2(K) = 4.84500	X2(K) = -0.84409
K= 904	Y2(K) = 4.84400	X2(K) = -0.84464
K= 905	Y2(K) = 4.84300	X2(K) = -0.84520
K= 906	Y2(K) = 4.84200	X2(K) = -0.84576
K= 907	Y2(K) = 4.84100	X2(K) = -0.84632
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K= 909	Y2(K) = 4.83900	X2(K) = -0.84746
K= 910	Y2(K) = 4.83800	X2(K) = -0.84804
K= 911	Y2(K) = 4.83700	X2(K) = -0.84863
K= 912	Y2(K) = 4.83600	X2(K) = -0.84922
K= 913	Y2(K) = 4.83500	X2(K) = -0.84981
K= 914	Y2(K) = 4.83400	X2(K) = -0.85041
K= 915	Y2(K) = 4.83300	X2(K) = -0.85102
K= 916	Y2(K) = 4.83200	X2(K) = -0.85160
K= 917	Y2(K) = 4.83100	X2(K) = -0.85217
K= 918	Y2(K) = 4.83000	X2(K) = -0.85274
K= 919	Y2(K) = 4.82900	X2(K) = -0.85332
K= 920	Y2(K) = 4.82800	X2(K) = -0.85391

K= 921	Y2(K) =	4.82700	X2(K) =	-0.85450
K= 922	Y2(K) =	4.82600	X2(K) =	-0.85509
K= 923	Y2(K) =	4.82500	X2(K) =	-0.85569
K= 924	Y2(K) =	4.82400	X2(K) =	-0.85629
K= 925	Y2(K) =	4.82300	X2(K) =	-0.85690
K= 926	Y2(K) =	4.82200	X2(K) =	-0.85752
K= 927	Y2(K) =	4.82100	X2(K) =	-0.85814
K= 928	Y2(K) =	4.82000	X2(K) =	-0.85877
K= 929	Y2(K) =	4.81900	X2(K) =	-0.85940
K= 930	Y2(K) =	4.81800	X2(K) =	-0.86004
K= 931	Y2(K) =	4.81700	X2(K) =	-0.86068
K= 932	Y2(K) =	4.81600	X2(K) =	-0.86133
K= 933	Y2(K) =	4.81500	X2(K) =	-0.86198
K= 934	Y2(K) =	4.81400	X2(K) =	-0.86264
K= 935	Y2(K) =	4.81300	X2(K) =	-0.86331
K= 936	Y2(K) =	4.81200	X2(K) =	-0.86395
K= 937	Y2(K) =	4.81100	X2(K) =	-0.86458
K= 938	Y2(K) =	4.81000	X2(K) =	-0.86521
K= 939	Y2(K) =	4.80900	X2(K) =	-0.86585
K= 940	Y2(K) =	4.80800	X2(K) =	-0.86650
K= 941	Y2(K) =	4.80700	X2(K) =	-0.86715
K= 942	Y2(K) =	4.80600	X2(K) =	-0.86780
K= 943	Y2(K) =	4.80500	X2(K) =	-0.86846
K= 944	Y2(K) =	4.80400	X2(K) =	-0.86913
K= 945	Y2(K) =	4.80300	X2(K) =	-0.86981
K= 946	Y2(K) =	4.80200	X2(K) =	-0.87048
K= 947	Y2(K) =	4.80100	X2(K) =	-0.87117
K= 948	Y2(K) =	4.80000	X2(K) =	-0.87186
K= 949	Y2(K) =	4.79900	X2(K) =	-0.87256
K= 950	Y2(K) =	4.79800	X2(K) =	-0.87326
K= 951	Y2(K) =	4.79700	X2(K) =	-0.87397
K= 952	Y2(K) =	4.79600	X2(K) =	-0.87469
K= 953	Y2(K) =	4.79500	X2(K) =	-0.87541
K= 954	Y2(K) =	4.79400	X2(K) =	-0.87614
K= 955	Y2(K) =	4.79300	X2(K) =	-0.87687
K= 956	Y2(K) =	4.79200	X2(K) =	-0.87756
K= 957	Y2(K) =	4.79100	X2(K) =	-0.87826
K= 958	Y2(K) =	4.79000	X2(K) =	-0.87896
K= 959	Y2(K) =	4.78900	X2(K) =	-0.87967
K= 960	Y2(K) =	4.78800	X2(K) =	-0.88039
K= 961	Y2(K) =	4.78700	X2(K) =	-0.88111
K= 962	Y2(K) =	4.78600	X2(K) =	-0.88183
K= 963	Y2(K) =	4.78500	X2(K) =	-0.88257
K= 964	Y2(K) =	4.78400	X2(K) =	-0.88331
K= 965	Y2(K) =	4.78300	X2(K) =	-0.88405
K= 966	Y2(K) =	4.78200	X2(K) =	-0.88480
K= 967	Y2(K) =	4.78100	X2(K) =	-0.88556
K= 968	Y2(K) =	4.78000	X2(K) =	-0.88633
K= 969	Y2(K) =	4.77900	X2(K) =	-0.88710
K= 970	Y2(K) =	4.77800	X2(K) =	-0.88788
K= 971	Y2(K) =	4.77700	X2(K) =	-0.88867
K= 972	Y2(K) =	4.77600	X2(K) =	-0.88946
K= 973	Y2(K) =	4.77500	X2(K) =	-0.89026
K= 974	Y2(K) =	4.77400	X2(K) =	-0.89107
K= 975	Y2(K) =	4.77300	X2(K) =	-0.89185
K= 976	Y2(K) =	4.77200	X2(K) =	-0.89261
K= 977	Y2(K) =	4.77100	X2(K) =	-0.89339
K= 978	Y2(K) =	4.77000	X2(K) =	-0.89417
K= 979	Y2(K) =	4.76900	X2(K) =	-0.89496
K= 980	Y2(K) =	4.76800	X2(K) =	-0.89575
K= 981	Y2(K) =	4.76700	X2(K) =	-0.89655
K= 982	Y2(K) =	4.76600	X2(K) =	-0.89736
K= 983	Y2(K) =	4.76500	X2(K) =	-0.89818
K= 984	Y2(K) =	4.76400	X2(K) =	-0.89900
K= 985	Y2(K) =	4.76300	X2(K) =	-0.89983
K= 986	Y2(K) =	4.76200	X2(K) =	-0.90067

K= 987	Y2(K) = 4.76100	X2(K) = -0.90152
K= 988	Y2(K) = 4.76000	X2(K) = -0.90237
K= 989	Y2(K) = 4.75900	X2(K) = -0.90323
K= 990	Y2(K) = 4.75800	X2(K) = -0.90410
K= 991	Y2(K) = 4.75700	X2(K) = -0.90497
K= 992	Y2(K) = 4.75600	X2(K) = -0.90586
K= 993	Y2(K) = 4.75500	X2(K) = -0.90675
K= 994	Y2(K) = 4.75400	X2(K) = -0.90760
K= 995	Y2(K) = 4.75300	X2(K) = -0.90845
K= 996	Y2(K) = 4.75200	X2(K) = -0.90931
K= 997	Y2(K) = 4.75100	X2(K) = -0.91018
K= 998	Y2(K) = 4.75000	X2(K) = -0.91105
K= 999	Y2(K) = 4.74900	X2(K) = -0.91194
K=1000	Y2(K) = 4.74800	X2(K) = -0.91283
K=1001	Y2(K) = 4.74700	X2(K) = -0.91372
K=1002	Y2(K) = 4.74600	X2(K) = -0.91463
K=1003	Y2(K) = 4.74500	X2(K) = -0.91554
K=1004	Y2(K) = 4.74400	X2(K) = -0.91647
K=1005	Y2(K) = 4.74300	X2(K) = -0.91740
K=1006	Y2(K) = 4.74200	X2(K) = -0.91834
K=1007	Y2(K) = 4.74100	X2(K) = -0.91929
K=1008	Y2(K) = 4.74000	X2(K) = -0.92024
K=1009	Y2(K) = 4.73900	X2(K) = -0.92121
K=1010	Y2(K) = 4.73800	X2(K) = -0.92219
K=1011	Y2(K) = 4.73700	X2(K) = -0.92317
K=1012	Y2(K) = 4.73600	X2(K) = -0.92413
K=1013	Y2(K) = 4.73500	X2(K) = -0.92508
K=1014	Y2(K) = 4.73400	X2(K) = -0.92603
K=1015	Y2(K) = 4.73300	X2(K) = -0.92699
K=1016	Y2(K) = 4.73200	X2(K) = -0.92795
K=1017	Y2(K) = 4.73100	X2(K) = -0.92893
K=1018	Y2(K) = 4.73000	X2(K) = -0.92992
K=1019	Y2(K) = 4.72900	X2(K) = -0.93092
K=1020	Y2(K) = 4.72800	X2(K) = -0.93192
K=1021	Y2(K) = 4.72700	X2(K) = -0.93294
K=1022	Y2(K) = 4.72600	X2(K) = -0.93396
K=1023	Y2(K) = 4.72500	X2(K) = -0.93500
K=1024	Y2(K) = 4.72400	X2(K) = -0.93604
K=1025	Y2(K) = 4.72300	X2(K) = -0.93710
K=1026	Y2(K) = 4.72200	X2(K) = -0.93816
K=1027	Y2(K) = 4.72100	X2(K) = -0.93924
K=1028	Y2(K) = 4.72000	X2(K) = -0.94032
K=1029	Y2(K) = 4.71900	X2(K) = -0.94142
K=1030	Y2(K) = 4.71800	X2(K) = -0.94247
K=1031	Y2(K) = 4.71700	X2(K) = -0.94352
K=1032	Y2(K) = 4.71600	X2(K) = -0.94459
K=1033	Y2(K) = 4.71500	X2(K) = -0.94566
K=1034	Y2(K) = 4.71400	X2(K) = -0.94674
K=1035	Y2(K) = 4.71300	X2(K) = -0.94784
K=1036	Y2(K) = 4.71200	X2(K) = -0.94894
K=1037	Y2(K) = 4.71100	X2(K) = -0.95006
K=1038	Y2(K) = 4.71000	X2(K) = -0.95119
K=1039	Y2(K) = 4.70900	X2(K) = -0.95233
K=1040	Y2(K) = 4.70800	X2(K) = -0.95348
K=1041	Y2(K) = 4.70700	X2(K) = -0.95464
K=1042	Y2(K) = 4.70600	X2(K) = -0.95582
K=1043	Y2(K) = 4.70500	X2(K) = -0.95700
K=1044	Y2(K) = 4.70400	X2(K) = -0.95820
K=1045	Y2(K) = 4.70300	X2(K) = -0.95942
K=1046	Y2(K) = 4.70200	X2(K) = -0.96064
K=1047	Y2(K) = 4.70100	X2(K) = -0.96181
K=1048	Y2(K) = 4.70000	X2(K) = -0.96299
K=1049	Y2(K) = 4.69900	X2(K) = -0.96418
K=1050	Y2(K) = 4.69800	X2(K) = -0.96539
K=1051	Y2(K) = 4.69700	X2(K) = -0.96660
K=1052	Y2(K) = 4.69600	X2(K) = -0.96783

K=1053	Y2(K) =	4.69500	X2(K) = -0.96907
K=1054	Y2(K) =	4.69400	X2(K) = -0.97033
K=1055	Y2(K) =	4.69300	X2(K) = -0.97160
K=1056	Y2(K) =	4.69200	X2(K) = -0.97289
K=1057	Y2(K) =	4.69100	X2(K) = -0.97418
K=1058	Y2(K) =	4.69000	X2(K) = -0.97550
K=1059	Y2(K) =	4.68900	X2(K) = -0.97683
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K=1061	Y2(K) =	4.68700	X2(K) = -0.97953
K=1062	Y2(K) =	4.68600	X2(K) = -0.98091
K=1063	Y2(K) =	4.68500	X2(K) = -0.98223
K=1064	Y2(K) =	4.68400	X2(K) = -0.98356
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K=1069	Y2(K) =	4.67900	X2(K) = -0.99042
K=1070	Y2(K) =	4.67800	X2(K) = -0.99184
K=1071	Y2(K) =	4.67700	X2(K) = -0.99329
K=1072	Y2(K) =	4.67600	X2(K) = -0.99474
K=1073	Y2(K) =	4.67500	X2(K) = -0.99622
K=1074	Y2(K) =	4.67400	X2(K) = -0.99772
K=1075	Y2(K) =	4.67300	X2(K) = -0.99924
K=1076	Y2(K) =	4.67200	X2(K) = -1.00077
K=1077	Y2(K) =	4.67100	X2(K) = -1.00233
K=1078	Y2(K) =	4.67000	X2(K) = -1.00383
K=1079	Y2(K) =	4.66900	X2(K) = -1.00533
K=1080	Y2(K) =	4.66800	X2(K) = -1.00686
K=1081	Y2(K) =	4.66700	X2(K) = -1.00840
K=1082	Y2(K) =	4.66600	X2(K) = -1.00996
K=1083	Y2(K) =	4.66500	X2(K) = -1.01155
K=1084	Y2(K) =	4.66400	X2(K) = -1.01315
K=1085	Y2(K) =	4.66300	X2(K) = -1.01478
K=1086	Y2(K) =	4.66200	X2(K) = -1.01644
K=1087	Y2(K) =	4.66100	X2(K) = -1.01812
K=1088	Y2(K) =	4.66000	X2(K) = -1.01982
K=1089	Y2(K) =	4.65900	X2(K) = -1.02155
K=1090	Y2(K) =	4.65800	X2(K) = -1.02331
K=1091	Y2(K) =	4.65700	X2(K) = -1.02509
K=1092	Y2(K) =	4.65600	X2(K) = -1.02680
K=1093	Y2(K) =	4.65500	X2(K) = -1.02852
K=1094	Y2(K) =	4.65400	X2(K) = -1.03027
K=1095	Y2(K) =	4.65300	X2(K) = -1.03205
K=1096	Y2(K) =	4.65200	X2(K) = -1.03386
K=1097	Y2(K) =	4.65100	X2(K) = -1.03570
K=1098	Y2(K) =	4.65000	X2(K) = -1.03756
K=1099	Y2(K) =	4.64900	X2(K) = -1.03947
K=1100	Y2(K) =	4.64800	X2(K) = -1.04140
K=1101	Y2(K) =	4.64700	X2(K) = -1.04337
K=1102	Y2(K) =	4.64600	X2(K) = -1.04537
K=1103	Y2(K) =	4.64500	X2(K) = -1.04742
K=1104	Y2(K) =	4.64400	X2(K) = -1.04946
K=1105	Y2(K) =	4.64300	X2(K) = -1.05144
K=1106	Y2(K) =	4.64200	X2(K) = -1.05346
K=1107	Y2(K) =	4.64100	X2(K) = -1.05551
K=1108	Y2(K) =	4.64000	X2(K) = -1.05761
K=1109	Y2(K) =	4.63900	X2(K) = -1.05974
K=1110	Y2(K) =	4.63800	X2(K) = -1.06193
K=1111	Y2(K) =	4.63700	X2(K) = -1.06416
K=1112	Y2(K) =	4.63600	X2(K) = -1.06644
K=1113	Y2(K) =	4.63500	X2(K) = -1.06877
K=1114	Y2(K) =	4.63400	X2(K) = -1.07116
K=1115	Y2(K) =	4.63300	X2(K) = -1.07361
K=1116	Y2(K) =	4.63200	X2(K) = -1.07593

K=1119	Y2(K) =	4.62900	X2(K) =	-1.08324
K=1120	Y2(K) =	4.62800	X2(K) =	-1.08581
K=1121	Y2(K) =	4.62700	X2(K) =	-1.08844
K=1122	Y2(K) =	4.62600	X2(K) =	-1.09116
K=1123	Y2(K) =	4.62500	X2(K) =	-1.09396
K=1124	Y2(K) =	4.62400	X2(K) =	-1.09685
K=1125	Y2(K) =	4.62300	X2(K) =	-1.09977
K=1126	Y2(K) =	4.62200	X2(K) =	-1.10260
K=1127	Y2(K) =	4.62100	X2(K) =	-1.10551
K=1128	Y2(K) =	4.62000	X2(K) =	-1.10853
K=1129	Y2(K) =	4.61900	X2(K) =	-1.11167
K=1130	Y2(K) =	4.61800	X2(K) =	-1.11492
K=1131	Y2(K) =	4.61700	X2(K) =	-1.11832
K=1132	Y2(K) =	4.61600	X2(K) =	-1.12187
K=1133	Y2(K) =	4.61500	X2(K) =	-1.12557

APPENDIX H

PROGRAM LEWIS ENVELOPE

```
C         LEWIS ENVELOPE
C
C
C         SEARCH FOR CONB (B) THAT GIVES LEWIS PARABOLA WHICH IS
C         TANGENT TO TOOTH PROFILE
C
C
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON RP,B,RB,THETA
      DIMENSION X1(180),Y1(180),X2(1000),Y2(1000)
      INTEGER BEGIN,FINISH
      REAL XC,XT,YT,YC,YTT,XTT,N
      REAL KADD
      READ(5,910)ISTOP
  910 FORMAT(I1)
   99 READ(5,51) N,BEFF,PD,THETAD,CAPTCS,RC
      READ(5,52) KADD
      READ(5,53) DELPSI,DELAL
      READ(5,54) DELCON,CONB
      READ(5,55) NRITE
      ISTOP = ISTOP - 1
   51 FORMAT(6F9.5)
   52 FORMAT(F9.5)
   53 FORMAT(2F9.5)
   54 FORMAT(2F9.5)
   55 FORMAT(I1)
      WRITE(6,1)N,BEFF,PD
    1 FORMAT('1','N =',F9.5,5X,'BEFF =',F9.5,5X,'PD =',F9.5)
      WRITE(6,3)THETAD,CAPTCS,RC
    3 FORMAT(//' THETAD =',F9.5,5X,'CAPTCS =',F9.5,5X,'RC =',F9.5)
      WRITE(6,2) KADD
    2 FORMAT(//' ','KADD =',F9.5,//)
      WRITE(6,4) DELAL,DELPSI,DELCON,CONB
    4 FORMAT(//' ','DELAL =',F9.5,5X,'DELPSI =',F9.5,5X,'DELCON= ',F9.5,
     15X,'CONB =',F9.5)
      PI = 3.14159
      Z = PI/180.
      THETA = THETAD*Z
      RP = N/(2.*PD)
      RB = RP*DCOS(THETA)
      RO = RP+KADD/PD
      B = BEFF/PD
      THETAB = CAPTCS*DCOS(THETA)/RB + 2.*(DTAN(THETA)-THETA)
      EPS = THETAB/2.DO + THETA
      THETBD = THETAB/Z
      EPSC = EPS/Z
      BALLOW = RP*DSIN(THETA)*DSIN(THETA)
      IF(BEFF.GT.BALLOW) GO TO 41
      IF(BEFF.LE.BALLOW) GO TO 42
C
C         ********************************
C         *****    TOOTH IS UNDERCUT  *****
C         ********************************
C
   41 A = (RP-B)*DTAN(THETA)
      DELTAD = 0.0
```

```
0044            TAU = EPS
0045            BT = RO
0046            C = RB
0047            RF=CEKKER(BT,C,1.D-16,1.D-18,100)
0048            ALPHIN = DSQRT(DABS(RF*RF-RB*RB))/RB
0049            ALPHF = DTAN(DARCOS(RB/RO))
0050            GAMT = (DSQRT(DABS(RF*RF-(RP-BEFF)**2)))/RP
0051            PSIIN = -A/RP + GAMT
0052            PSIF = -A/RP
0053            WRITE(6,65)
0054         65 FORMAT(//' *****   TOOTH IS UNDERCUT   *****'//)
0055            GO TO 43
          C
          C        *************************************
          C        *****   TOOTH IS NOT UNDERCUT  *****
          C        *************************************
          C
0056         42 A = B/DTAN(THETA)
0057            DELTA = B/(RB*DSIN(THETA)) - DTAN(THETA)
0058            DELTAD = DELTA/Z
0059            TAU = EPS + DELTA
0060            RF = DSQRT(DABS((RB*DTAN(THETA)-B/DSIN(THETA))**2+RB*RB))
0061            GAMT = 0.0
0062            ALPHIN = DSQRT(DABS(RF*RF-RB*RB))/RB
0063            IF (ALPHIN.LE.0.001) ALPHIN = 0
0064            ALPHF = DTAN(DARCOS(RB/RO))
0065            PSIIN = 0.0
0066            PSIF = -A/RP
0067            WRITE(6,66)
0068         66 FORMAT(//' *****   TOOTH IS NOT UNDERCUT   *****'//)
0069         43 CONTINUE
0070            WRITE(6,70) RP,RB,RO,RF
0071         70 FORMAT(' RP =',F9.5,5X,'RB =',F9.5,5X,'RO =',F9.5,5X,'RF =',F9.5/)
0072            TAUD = TAU/Z
0073            GAMTD = GAMT/Z
0074            WRITE(6,71) THETBD,GAMTD,EPSD,DELTAD,TAUD
0075         71 FORMAT(/' THETAB =',F9.5,5X,'GAMT =',F9.5,5X,'EPS =',F9.5,5X,'DELT
               1A =',F9.5,5X,'TAU =',F9.5)
          C
          C        *************************************
          C        *****   FOR ALL TYPES OF TEETH   *****
          C        *************************************
          C
0076            PSIFD = PSIF/Z
0077            B2 = B - RC*DSIN(THETA)
0078            A2 = A - RC*DCOS(THETA)
0079            ALIND = ALPHIN/Z
0080            ALFIND = ALPHF/Z
0081            WRITE(6,5) ALIND,ALFIND
0082          5 FORMAT(//' ','ALPHIN =',F9.5,5X,'ALPHFIN =',F9.5)
          C
          C
          C
          C        INVOLUTE  PLOT
          C
          C
          C
0083            I = 1
```

```
0084            ALPHA = ALPHIN
0085         10 XI = RB*(-DSIN(THETAB*.5-ALPHA)-ALPHA*DCOS(THETAB*.5-ALPHA))
0086            YI = RB*(DCOS(THETAB*.5-ALPHA)-ALPHA*DSIN(THETAB*.5-ALPHA))
0087            X1(I) = XI
0088            Y1(I) = YI
0089            IF (ALPHA.GE.ALPHF)GO TO 20
0090            ALPHA = ALPHA + DELAL*Z
0091            I = I+1
0092            IPREV = I
0093            GO TO 10
      C
      C
      C            REVERSE ORDER TO DESCEND
      C
      C
0094         20 DO 16 K=1,I
0095            J = I - (K-1)
0096            X2(J) = X1(K)
0097            Y2(J) = Y1(K)
0098         16 CONTINUE
      C
      C            ******************************
      C            *****    TROCHOID PLO.    *****
      C            ******************************
      C
0099            PSI = PSIIN
0100            PSID = PSI/Z
0101            WRITE(6,6) PSID,PSIFD
0102          6 FORMAT(//' ','PSIIN =',F9.5,5X,'PSIFIN =',F9.5)
0103            I = IPREV + 1
0104        151 XENV= -(RP-B2)*DSIN(TAU+PSI)+(RP*PSI+A2)*DCOS(TAU+PSI)+
               1RC*((RP*PSI+A2)*DCOS(TAU+PSI)+B2*DSIN(TAU+PSI))/
               1DSQRT((RP*PSI+A2)**2+B2**2)
0105            YENV= (RP-B2)*DCOS(TAU+PSI)+(RP*PSI+A2)*DSIN(TAU+PSI)+
               1RC*((RP*PSI+A2)*DSIN(TAU+PSI)-B2*DCOS(TAU+PSI))/
               1DSQRT((RP*PSI+A2)**2+B2**2)
0106            X2(I) = XENV
0107            Y2(I) = YENV
0108            PSID = PSID - DELPSI
0109            PSI = PSID*Z
0110            IF(PSID.LE.PSIFD) GO TO 500
0111            I = I + 1
0112            GO TO 151
0113        500 KFIN = I
      C
      C
      C            DETERMINATION OF DISTANCE RV
      C
      C
0114         21 PHIRO = DARCOS(RB/RO)
0115            PHIROD = PHIRO/Z
0116            BETA = DARCOS(RB/RO)-CAPTCS/(2*RP)+DTAN(PHIRO)-PHIRO-DTAN(THETA)+
               1THETA
0117            BETAD = BETA/Z
0118            CAPTO = CAPTCS*RO/RP-2*RO*(DTAN(PHIRO)-PHIRO-DTAN(THETA)+THETA)
0119            THETAO = CAPTO/(2.*RO)
0120            THEOD = THETAO/Z
0121            RV = RO*(DCOS(THETAO)-DSIN(THETAO)*DTAN(BETA))
```

```
      WRITE(6,100) PHIROD,BETAD,CAPTO,THEOD
  100 FORMAT(//' PHIRO =',F9.5,5X,'BETA =',F9.5,5X,'CAPTO =',F9.5,5X,
     1'THETAD =',F9.5//)
      WRITE(6,101) RV
  101 FORMAT(' RV =',F9.5//)
C
C
C        LOCATION OF POINT V IN ARRAY Y2(K)
C
C
      START = RV - .005
      I = 1
  102 DIFF1 = Y2(I) - START
      IF(DIFF1.LE.0.0) GO TO 103
      I = I + 1
      GO TO 102
C
C
C        DETERMINATION OF TANGENCY POINT
C
C
  103 BEGIN = I
      KFIN1 = KFIN - BEGIN
  104 DO 105 J=1,KFIN1
      K = BEGIN + J - 1
      XPAR = DSQRT((RV-DABS(Y2(K)))/CONB)
      DIFF2 = DABS(X2(K)) - XPAR
      IF(DIFF2.LE.0.0) GO TO 109
  105 CONTINUE
      CONB = CONB - DELCON
      GO TO 104
C
C
C        DETERMINATION OF LEWIS AND AGMA FACTORS
C
C
  109 EX = X2(K)**2/(RV-Y2(K))
      YLEWIS = 2.D0*PD*EX/3
      YAGMA = 1.D0/(DCOS(BETA)/DCOS(THETA)*(1.5D0/EX -
     1DTAN(BETA)/(2.D0*X2(K))))
      WRITE(6,111) EX,YLEWIS,YAGMA
  111 FORMAT(//' ','EX =',F9.5,5X,'YLEWIS =',F9.5,5X,'YAGMA =',F9.5)
      WRITE(6,110) K,Y2(K),X2(K),XPAR,CONB
  110 FORMAT(//' TANGENCY K =',I3,5X,'Y2(KTAN) =',F9.5,5X,'X2(KTAN) =',
     1F9.6,5X,'XPAR TAN =',F9.6,5X,'CONB =',F6.3/)
      WRITE(6,31) NRITE
   31 FORMAT(//' ',10X,'NRITE =',I1/'1')
      IF(NRITE.EQ.0) GO TO 999
C
C
C        THIS WILL PRINT THE FULL TOOTH PROFILEO  K,X2(K),Y2(K)
C
C
      WRITE(6,56)
   56 FORMAT(//' ','     INVOLUTE  PLOT     '//)
   61 DO 63 K=1,IPREV
      WRITE(6,64) K,Y2(K),X2(K)
   64 FORMAT(' K=',I4,5X,'Y2(K) =',F10.5,5X,'X2(K) =',F10.5)
```

```
   63 CONTINUE
      WRITE(6,57)
   57 FORMAT(//' ','      TROCHOID  PLOT     '//)
      KFIN = KFIN - IPREV
      DO 67 I=1,KFIN
      K = I + IPREV
      WRITE(6,68) K,Y2(K),X2(K)
   68 FORMAT(' K=',I4,5X,'Y2(K) =',F10.5,5X,'X2(K) =',F10.5)
   67 CONTINUE
  999 IF(ISTOP.GT.0) GO TO 99
      STOP
      END
```

```
0001            DOUBLE PRECISION FUNCTION DEKKER(B,C,EPS,TOL,LIMIT)
          C
          C*******************************************************************
          C
          C TITLE- DEKKER'S ALGORITHM
          C
          C PURPOSE- TO FIND A ROOT OF A NON-LINEAR ALGEBRAIC EQUATION F(X)=0.
          C DESCRIPTION OF PARAMETERS
          C     B = THE LATEST ITERATE AND CLOSEST APPROXIMATION TO THE ROOT.
          C     A = THE PREVIOUS ITERATE.
          C     C = THE PREVIOUS OR AN OLDER ITERATE.
          C COMMENTS
          C     AT ALL TIMES B AND C BRACKET THE ROOT.
          C     INITIALLY A IS SET EQUAL TO C.
          C     USE EPS=1.D-7 AND TOL=1.D-10.
          C SUBROUTINES AND/OR FUNCTION SUBPROGRAMS REQUIRED- F(X)
          C*******************************************************************
0002            IMPLICIT REAL*8 (A-H,O-Z)
0003            A=C
0004            KOUNT=-1
0005            FOA=F(A)
0006            FOB=F(B)
0007            FOC=F(C)
0008            IF((FOB*FOC).GT.0.D0)GO TO 6
0009          8 KOUNT=KOUNT+1
0010            IF(DABS(FOB).LE.DABS(FOC))GO TO 7
0011            T=B
0012            B=C
0013            DEKKER=B
0014            C=T
0015            A=C
0016            T=FOB
0017            FOB=FOC
0018            FOC=T
0019            FOA=FOC
0020          7 IF(FOB.EQ.0.D0)RETURN
0021            TOL1=2.D0*EPS*DABS(B)+0.5D0*TOL
0022            IF(DABS(B-C).LE.2.D0*TOL1)RETURN
0023            IF(DABS(FOB-FOA).LT.1.D-70)RETURN
0024            IF(KOUNT.GE.LIMIT)GO TO 12
0025            DI=A-((B-A)*FOA)/(FOB-FOA)
0026            BP=DI
0027            IF(.NOT.(((C.LE.DI).AND.(DI.LE.B)).OR.((B.LE.DI).AND.(DI.LE.C))))
               1 BP=(B+C)/2.D0
0028            IF((((C.LE.DI).AND.(DI.LE.B)).OR.((B.LE.DI).AND.(DI.LE.C)))
               1 .AND.(DABS(DI-B).LT.TOL1))BP=B+DSIGN(TOL1,(C-B))
0029            IF(DABS(DI-C).LT.DABS(B-C)/4.D0)BP=(B+C)/2.D0
0030            A=B
0031            FOA=FOB
0032            B=BP
0033            DEKKER=B
0034            FOB=F(B)
0035            IF((FOB*FOC).GT.0.D0)C=A
0036            IF((FOB*FOC).GT.0.D0)FOC=FOA
0037            GO TO 8
0038          6 WRITE(6,15)
0039            STOP
0040         12 WRITE(6,13)
```

```
C041          STCP
CC42       15 FORPAT('-','ERROR IN INPUT DSTA.  F(B) HAS THE SAME SIGN AS',
             1 ' F(C)')
C043       13 FORPAT('-','NUMBER OF ITERATIONS HAS EXCEEDED LIMIT.  STOP COPPUTA
             1TICNS.')
C044          ENC
```

```
FORTRAN IV G LEVEL  21                F                DATE = 81159        15/15/27              PAGE 0001

 0001                COUBLE PRECISION FUNCTION F(X)
 0002                IMPLICIT REAL*8 (A-H,O-Z)
 0003                COMMON RP,B,RB,THETA
 0004                F=DATAN(DSQRT(X**2-(RP-B )**2)/(RP-B ))-DSQRT(X**2-(RP-B )**2)/RP
                    1-THETA*(RP-B )*DTAN(THETA)/RP-DSQRT(X**2-RB**2)/RB+DATAN(DSQRT(X
                    2**2-RB**2)/RB)
 0005                RETURN
 0006                END
```

```
N = 36.00000     BEFF = 1.21500     PD = 1.00000

THETAC = 20.00000     CAPTCS = 1.84600     RC = 0.04000

KACC = 1.42500


DELAL = 0.25000     CELPSI = 0.12500     DELCON= 0.00100     CONB = 5.00000

*****   TOOTH IS NOT UNDERCUT   *****

RP = 18.00000     RB = 16.91447     RO = 19.42500     RF = 17.11373

THETAB = 7.58392     GAMT = 0.0     EPS = 23.79196     DELTA = -8.82052     TAU = 14.97144

ALPHIN = 8.82052     ALPHFIN = 32.35465

PSIIN = 0.0     PSIFIN =-10.62580

PHIRO = 29.45321     BETA = 28.56269     CAPTO = 0.60383     THETAO = 0.89052

RV = 19.25831


EX = 0.55277     YLEWIS = 0.36851     YAGMA = 0.36221

TANGENCY K =117     Y2(KTAN) = 16.93642     X2(KTAN) =-1.132901     XPAR TAN = 1.132924     CONB = 1.809

     NRITE =1
```

INVOLUTE PLOT

K=	1	Y2(K) =	19.45633	X2(K) =	-0.28458
K=	2	Y2(K) =	19.41700	X2(K) =	-0.30462
K=	3	Y2(K) =	19.38118	X2(K) =	-0.32435
K=	4	Y2(K) =	19.34490	X2(K) =	-0.34376
K=	5	Y2(K) =	19.30882	X2(K) =	-0.36287
K=	6	Y2(K) =	19.27294	X2(K) =	-0.38167
K=	7	Y2(K) =	19.23727	X2(K) =	-0.40016
K=	8	Y2(K) =	19.20180	X2(K) =	-0.41835
K=	9	Y2(K) =	19.16654	X2(K) =	-0.43625
K=	10	Y2(K) =	19.13149	X2(K) =	-0.45384
K=	11	Y2(K) =	19.09665	X2(K) =	-0.47113
K=	12	Y2(K) =	19.06203	X2(K) =	-0.48814
K=	13	Y2(K) =	19.02762	X2(K) =	-0.50485
K=	14	Y2(K) =	18.99343	X2(K) =	-0.52127
K=	15	Y2(K) =	18.95946	X2(K) =	-0.53740
K=	16	Y2(K) =	18.92571	X2(K) =	-0.55325
K=	17	Y2(K) =	18.89218	X2(K) =	-0.56881
K=	18	Y2(K) =	18.85888	X2(K) =	-0.58410
K=	19	Y2(K) =	18.82581	X2(K) =	-0.59910
K=	20	Y2(K) =	18.79296	X2(K) =	-0.61383
K=	21	Y2(K) =	18.76039	X2(K) =	-0.62829
K=	22	Y2(K) =	18.72796	X2(K) =	-0.64247
K=	23	Y2(K) =	18.69582	X2(K) =	-0.65639
K=	24	Y2(K) =	18.66390	X2(K) =	-0.67003
K=	25	Y2(K) =	18.63223	X2(K) =	-0.68342
K=	26	Y2(K) =	18.60079	X2(K) =	-0.69654
K=	27	Y2(K) =	18.56960	X2(K) =	-0.70940
K=	28	Y2(K) =	18.53864	X2(K) =	-0.72200
K=	29	Y2(K) =	18.50793	X2(K) =	-0.73435
K=	30	Y2(K) =	18.47747	X2(K) =	-0.74644
K=	31	Y2(K) =	18.44725	X2(K) =	-0.75829
K=	32	Y2(K) =	18.41729	X2(K) =	-0.76988
K=	33	Y2(K) =	18.38757	X2(K) =	-0.78123
K=	34	Y2(K) =	18.35810	X2(K) =	-0.79234
K=	35	Y2(K) =	18.32889	X2(K) =	-0.80320
K=	36	Y2(K) =	18.29994	X2(K) =	-0.81383
K=	37	Y2(K) =	18.27124	X2(K) =	-0.82422
K=	38	Y2(K) =	18.24280	X2(K) =	-0.83438
K=	39	Y2(K) =	18.21462	X2(K) =	-0.84431
K=	40	Y2(K) =	18.18670	X2(K) =	-0.85400
K=	41	Y2(K) =	18.15904	X2(K) =	-0.86347
K=	42	Y2(K) =	18.13165	X2(K) =	-0.87272
K=	43	Y2(K) =	18.10452	X2(K) =	-0.88175
K=	44	Y2(K) =	18.07766	X2(K) =	-0.89056
K=	45	Y2(K) =	18.05108	X2(K) =	-0.89915
K=	46	Y2(K) =	18.02474	X2(K) =	-0.90752
K=	47	Y2(K) =	17.99869	X2(K) =	-0.91569
K=	48	Y2(K) =	17.97291	X2(K) =	-0.92365
K=	49	Y2(K) =	17.94740	X2(K) =	-0.93140
K=	50	Y2(K)	17.92217	X2(K) =	-0.93895
K=	51	Y2(K) =	17.89722	X2(K) =	-0.94629
K=	52	Y2(K) =	17.87254	X2(K) =	-0.95344
K=	53	Y2(K) =	17.84814	X2(K) =	-0.96039
K=	54	Y2(K) =	17.82402	X2(K) =	-0.96715
K=	55	Y2(K) =	17.80018	X2(K) =	-0.97372

K=	56	Y2(K) =	17.77665	X2(K) =	-0.98010
K=	57	Y2(K) =	17.75336	X2(K) =	-0.98629
K=	58	Y2(K) =	17.73037	X2(K) =	-0.99230
K=	59	Y2(K) =	17.70767	X2(K) =	-0.99813
K=	60	Y2(K) =	17.68525	X2(K) =	-1.00379
K=	61	Y2(K) =	17.66313	X2(K) =	-1.00926
K=	62	Y2(K) =	17.64129	X2(K) =	-1.01457
K=	63	Y2(K) =	17.61974	X2(K) =	-1.01970
K=	64	Y2(K) =	17.59849	X2(K) =	-1.02467
K=	65	Y2(K) =	17.57753	X2(K) =	-1.02947
K=	66	Y2(K) =	17.55686	X2(K) =	-1.03411
K=	67	Y2(K) =	17.53648	X2(K) =	-1.03859
K=	68	Y2(K) =	17.51640	X2(K) =	-1.04292
K=	69	Y2(K) =	17.49662	X2(K) =	-1.04709
K=	70	Y2(K) =	17.47714	X2(K) =	-1.05111
K=	71	Y2(K) =	17.45795	X2(K) =	-1.05498
K=	72	Y2(K) =	17.43906	X2(K) =	-1.05870
K=	73	Y2(K) =	17.42047	X2(K) =	-1.06228
K=	74	Y2(K) =	17.40219	X2(K) =	-1.06572
K=	75	Y2(K) =	17.38420	X2(K) =	-1.06902
K=	76	Y2(K) =	17.36652	X2(K) =	-1.07219
K=	77	Y2(K) =	17.34914	X2(K) =	-1.07523
K=	78	Y2(K) =	17.33207	X2(K) =	-1.07813
K=	79	Y2(K) =	17.31530	X2(K) =	-1.08091
K=	80	Y2(K) =	17.29884	X2(K) =	-1.08356
K=	81	Y2(K) =	17.28268	X2(K) =	-1.08609
K=	82	Y2(K) =	17.26683	X2(K) =	-1.08850
K=	83	Y2(K) =	17.25129	X2(K) =	-1.09080
K=	84	Y2(K) =	17.23606	X2(K) =	-1.09298
K=	85	Y2(K) =	17.22114	X2(K) =	-1.09505
K=	86	Y2(K) =	17.20653	X2(K) =	-1.09702
K=	87	Y2(K) =	17.19223	X2(K) =	-1.09887
K=	88	Y2(K) =	17.17824	X2(K) =	-1.10063
K=	89	Y2(K) =	17.16456	X2(K) =	-1.10229
K=	90	Y2(K) =	17.15119	X2(K) =	-1.10385
K=	91	Y2(K) =	17.13814	X2(K) =	-1.10531
K=	92	Y2(K) =	17.12541	X2(K) =	-1.10668
K=	93	Y2(K) =	17.11298	X2(K) =	-1.10797
K=	94	Y2(K) =	17.10088	X2(K) =	-1.10917
K=	95	Y2(K) =	17.08908	X2(K) =	-1.11028
K=	96	Y2(K) =	17.07761	X2(K) =	-1.11132

TROCHOID PLOT

K=	97	Y2(K) =	17.07761	X2(K) =	-1.11132
K=	98	Y2(K) =	17.06978	X2(K) =	-1.11203
K=	99	Y2(K) =	17.06203	X2(K) =	-1.11278
K=	100	Y2(K) =	17.05436	X2(K) =	-1.11358
K=	101	Y2(K) =	17.04677	X2(K) =	-1.11441
K=	102	Y2(K) =	17.03926	X2(K) =	-1.11528
K=	103	Y2(K) =	17.03185	X2(K) =	-1.11619
K=	104	Y2(K) =	17.02449	X2(K) =	-1.11714
K=	105	Y2(K) =	17.01723	X2(K) =	-1.11813
K=	106	Y2(K) =	17.01005	X2(K) =	-1.11916
K=	107	Y2(K) =	17.00295	X2(K) =	-1.12022
K=	108	Y2(K) =	16.99593	X2(K) =	-1.12132
K=	109	Y2(K) =	16.98899	X2(K) =	-1.12246
K=	110	Y2(K) =	16.98213	X2(K) =	-1.12364
K=	111	Y2(K) =	16.97536	X2(K) =	-1.12485

K=	112	Y2(K) =	16.96867	X2(K) =	-1.12611
K=	113	Y2(K) =	16.96206	X2(K) =	-1.12739
K=	114	Y2(K) =	16.95555	X2(K) =	-1.12872
K=	115	Y2(K) =	16.94908	X2(K) =	-1.13007
K=	116	Y2(K) =	16.94271	X2(K) =	-1.13147
K=	117	Y2(K) =	16.93642	X2(K) =	-1.13290
K=	118	Y2(K) =	16.93022	X2(K) =	-1.13437
K=	119	Y2(K) =	16.92409	X2(K) =	-1.13587
K=	120	Y2(K) =	16.91805	X2(K) =	-1.13741
K=	121	Y2(K) =	16.91209	X2(K) =	-1.13898
K=	122	Y2(K) =	16.90621	X2(K) =	-1.14058
K=	123	Y2(K) =	16.90041	X2(K) =	-1.14223
K=	124	Y2(K) =	16.89469	X2(K) =	-1.14390
K=	125	Y2(K) =	16.88905	X2(K) =	-1.14561
K=	126	Y2(K) =	16.88350	X2(K) =	-1.14736
K=	127	Y2(K) =	16.87802	X2(K) =	-1.14914
K=	128	Y2(K) =	16.87263	X2(K) =	-1.15095
K=	129	Y2(K) =	16.86731	X2(K) =	-1.15280
K=	130	Y2(K) =	16.86207	X2(K) =	-1.15468
K=	131	Y2(K) =	16.85692	X2(K) =	-1.15660
K=	132	Y2(K) =	16.85184	X2(K) =	-1.15855
K=	133	Y2(K) =	16.84685	X2(K) =	-1.16053
K=	134	Y2(K) =	16.84194	X2(K) =	-1.16256
K=	135	Y2(K) =	16.83710	X2(K) =	-1.16461
K=	136	Y2(K) =	16.83234	X2(K) =	-1.16670
K=	137	Y2(K) =	16.82767	X2(K) =	-1.16883
K=	138	Y2(K) =	16.82307	X2(K) =	-1.17099
K=	139	Y2(K) =	16.81856	X2(K) =	-1.17318
K=	140	Y2(K) =	16.81412	X2(K) =	-1.17542
K=	141	Y2(K) =	16.80976	X2(K) =	-1.17768
K=	142	Y2(K) =	16.80548	X2(K) =	-1.17999
K=	143	Y2(K) =	16.80128	X2(K) =	-1.18233
K=	144	Y2(K) =	16.79716	X2(K) =	-1.18471
K=	145	Y2(K) =	16.79312	X2(K) =	-1.18713
K=	146	Y2(K) =	16.78916	X2(K) =	-1.18959
K=	147	Y2(K) =	16.78528	X2(K) =	-1.19208
K=	148	Y2(K) =	16.78147	X2(K) =	-1.19462
K=	149	Y2(K) =	16.77775	X2(K) =	-1.19720
K=	150	Y2(K) =	16.77411	X2(K) =	-1.19981
K=	151	Y2(K) =	16.77059	X2(K) =	-1.20247
K=	152	Y2(K) =	16.76707	X2(K) =	-1.20518
K=	153	Y2(K) =	16.76367	X2(K) =	-1.20792
K=	154	Y2(K) =	16.76035	X2(K) =	-1.21072
K=	155	Y2(K) =	16.75711	X2(K) =	-1.21356
K=	156	Y2(K) =	16.75398	X2(K) =	-1.21644
K=	157	Y2(K) =	16.75090	X2(K) =	-1.21937
K=	158	Y2(K) =	16.74791	X2(K) =	-1.22235
K=	159	Y2(K) =	16.74502	X2(K) =	-1.22538
K=	160	Y2(K) =	16.74222	X2(K) =	-1.22847
K=	161	Y2(K) =	16.73950	X2(K) =	-1.23160
K=	162	Y2(K) =	16.73688	X2(K) =	-1.23478
K=	163	Y2(K) =	16.73435	X2(K) =	-1.23802
K=	164	Y2(K) =	16.73191	X2(K) =	-1.24131
K=	165	Y2(K) =	16.72958	X2(K) =	-1.24465
K=	166	Y2(K) =	16.72734	X2(K) =	-1.24805
K=	167	Y2(K) =	16.72521	X2(K) =	-1.25150
K=	168	Y2(K) =	16.72318	X2(K) =	-1.25500
K=	169	Y2(K) =	16.72128	X2(K) =	-1.25856
K=	170	Y2(K) =	16.71948	X2(K) =	-1.26216
K=	171	Y2(K) =	16.71777	X2(K) =	-1.26582
K=	172	Y2(K) =	16.71620	X2(K) =	-1.26952

K= 173	Y2(K) = 16.71475	X2(K) = -1.27327
K= 174	Y2(K) = 16.71342	X2(K) = -1.27707
K= 175	Y2(K) = 16.71222	X2(K) = -1.28090
K= 176	Y2(K) = 16.71115	X2(K) = -1.28477
K= 177	Y2(K) = 16.71021	X2(K) = -1.28868
K= 178	Y2(K) = 16.70941	X2(K) = -1.29261
K= 179	Y2(K) = 16.70879	X2(K) = -1.29657
K= 180	Y2(K) = 16.70822	X2(K) = -1.30055
K= 181	Y2(K) = 16.70789	X2(K) = -1.30455
K= 182	Y2(K) = 16.70758	X2(K) = -1.30856

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N = 12.00000     BEFF = 1.05260     PD = 1.00000

THETAC = 20.00000     CAPTCS = 1.57079     RC = 0.30000

KADC = 1.00000


DELAL = 0.25000     CELPSI = 0.50000     DELCON= 0.00100     CONB = 4.00000

*****   TOOTH IS UNDERCUT   *****

RP = 6.00000     RB = 5.63816     RO = 7.00000     RF = 5.65550

THETAB = 16.70787     GAMT = 26.16565     EPS = 28.35393     DELTA = 0.0     TAU = 28.35393

ALPHIN = 4.49751     ALPHFIN = 42.15911

PSIIN = 8.97017     PSIFIN =-17.19548

PHIRC = 36.34621     BETA = 33.80518     CAPTO = 0.62089     THETAQ = 2.54104

RV = 6.78532


EX = 0.34443     YLEWIS = 0.22962     YAGMA = 0.23643

TANGENCY K =177     Y2(KTAN) = 5.01112     X2(KTAN) =-0.781725     XPAR TAN = 0.781767     CONB = 2.903

     NRITE =1
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AD-A117 593 CITY COLL RESEARCH FOUNDATION NEW YORK F/G 19/1
AUTOMATED STRENGTH DETERMINATION FOR INVOLUTE FUZE GEARS.(U)
FEB 82 G G LOWEN, C KAPLAN DAAK10-79-C-0251
UNCLASSIFIED ARLCD-CR-81060 NL

3 of 3

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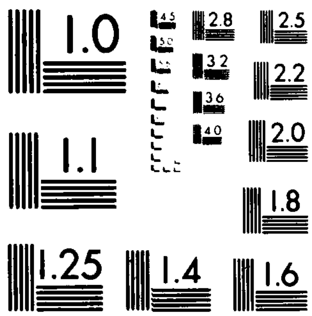

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A

INVOLUTE PLOT

K=	1	Y2(K) =	6.99844	X2(K) =	-0.30677
K=	2	Y2(K) =	6.98340	X2(K) =	-0.31583
K=	3	Y2(K) =	6.96541	X2(K) =	-0.32676
K=	4	Y2(K) =	6.95347	X2(K) =	-0.33656
K=	5	Y2(K) =	6.93958	X2(K) =	-0.34624
K=	6	Y2(K) =	6.92373	X2(K) =	-0.35580
K=	7	Y2(K) =	6.90893	X2(K) =	-0.36523
K=	8	Y2(K) =	6.89418	X2(K) =	-0.37454
K=	9	Y2(K) =	6.87949	X2(K) =	-0.38373
K=	10	Y2(K) =	6.86484	X2(K) =	-0.39280
K=	11	Y2(K) =	6.85025	X2(K) =	-0.40175
K=	12	Y2(K) =	6.83570	X2(K) =	-0.41058
K=	13	Y2(K) =	6.82122	X2(K) =	-0.41930
K=	14	Y2(K) =	6.80678	X2(K) =	-0.42789
K=	15	Y2(K) =	6.79240	X2(K) =	-0.43636
K=	16	Y2(K) =	6.77808	X2(K) =	-0.44472
K=	17	Y2(K) =	6.76382	X2(K) =	-0.45297
K=	18	Y2(K) =	6.74961	X2(K) =	-0.46109
K=	19	Y2(K) =	6.73546	X2(K) =	-0.46911
K=	20	Y2(K) =	6.72137	X2(K) =	-0.47700
K=	21	Y2(K) =	6.70733	X2(K) =	-0.48479
K=	22	Y2(K) =	6.69336	X2(K) =	-0.49246
K=	23	Y2(K) =	6.67945	X2(K) =	-0.50002
K=	24	Y2(K) =	6.66560	X2(K) =	-0.50746
K=	25	Y2(K) =	6.65181	X2(K) =	-0.51480
K=	26	Y2(K) =	6.63809	X2(K) =	-0.52203
K=	27	Y2(K) =	6.62443	X2(K) =	-0.52914
K=	28	Y2(K) =	6.61084	X2(K) =	-0.53615
K=	29	Y2(K) =	6.59731	X2(K) =	-0.54305
K=	30	Y2(K) =	6.58384	X2(K) =	-0.54984
K=	31	Y2(K) =	6.57044	X2(K) =	-0.55653
K=	32	Y2(K) =	6.55711	X2(K) =	-0.56311
K=	33	Y2(K) =	6.54385	X2(K) =	-0.56958
K=	34	Y2(K) =	6.53066	X2(K) =	-0.57595
K=	35	Y2(K) =	6.51753	X2(K) =	-0.58222
K=	36	Y2(K) =	6.50448	X2(K) =	-0.58838
K=	37	Y2(K) =	6.49149	X2(K) =	-0.59444
K=	38	Y2(K) =	6.47858	X2(K) =	-0.60040
K=	39	Y2(K) =	6.46574	X2(K) =	-0.60625
K=	40	Y2(K) =	6.45297	X2(K) =	-0.61201
K=	41	Y2(K) =	6.44027	X2(K) =	-0.61767
K=	42	Y2(K) =	6.42765	X2(K) =	-0.62323
K=	43	Y2(K) =	6.41510	X2(K) =	-0.62869
K=	44	Y2(K) =	6.40263	X2(K) =	-0.63405
K=	45	Y2(K) =	6.39029	X2(K) =	-0.63932
K=	46	Y2(K) =	6.37791	X2(K) =	-0.64449
K=	47	Y2(K) =	6.36566	X2(K) =	-0.64957
K=	48	Y2(K) =	6.35349	X2(K) =	-0.65455
K=	49	Y2(K) =	6.34140	X2(K) =	-0.65944
K=	50	Y2(K) =	6.32939	X2(K) =	-0.66424
K=	51	Y2(K) =	6.31748	X2(K) =	-0.66894
K=	52	Y2(K) =	6.30561	X2(K) =	-0.67356
K=	53	Y2(K) =	6.29384	X2(K) =	-0.67808
K=	54	Y2(K) =	6.28214	X2(K) =	-0.68251
K=	55	Y2(K) =	6.27053	X2(K) =	-0.68686

K= 56	Y2(K) = 6.25900	X2(K) = -0.69112
K= 57	Y2(K) = 6.24750	X2(K) = -0.69529
K= 58	Y2(K) = 6.23620	X2(K) = -0.69937
K= 59	Y2(K) = 6.22492	X2(K) = -0.70337
K= 60	Y2(K) = 6.21372	X2(K) = -0.70728
K= 61	Y2(K) = 6.20261	X2(K) = -0.71111
K= 62	Y2(K) = 6.19158	X2(K) = -0.71486
K= 63	Y2(K) = 6.18064	X2(K) = -0.71852
K= 64	Y2(K) = 6.16979	X2(K) = -0.72211
K= 65	Y2(K) = 6.15902	X2(K) = -0.72561
K= 66	Y2(K) = 6.14834	X2(K) = -0.72903
K= 67	Y2(K) = 6.13774	X2(K) = -0.73238
K= 68	Y2(K) = 6.12724	X2(K) = -0.73564
K= 69	Y2(K) = 6.11682	X2(K) = -0.73883
K= 70	Y2(K) = 6.10649	X2(K) = -0.74194
K= 71	Y2(K) = 6.09629	X2(K) = -0.74498
K= 72	Y2(K) = 6.08611	X2(K) = -0.74794
K= 73	Y2(K) = 6.07605	X2(K) = -0.75083
K= 74	Y2(K) = 6.06608	X2(K) = -0.75364
K= 75	Y2(K) = 6.05620	X2(K) = -0.75639
K= 76	Y2(K) = 6.04642	X2(K) = -0.75906
K= 77	Y2(K) = 6.03673	X2(K) = -0.76166
K= 78	Y2(K) = 6.02713	X2(K) = -0.76419
K= 79	Y2(K) = 6.01762	X2(K) = -0.76665
K= 80	Y2(K) = 6.00820	X2(K) = -0.76905
K= 81	Y2(K) = 5.99888	X2(K) = -0.77137
K= 82	Y2(K) = 5.98966	X2(K) = -0.77363
K= 83	Y2(K) = 5.98053	X2(K) = -0.77583
K= 84	Y2(K) = 5.97149	X2(K) = -0.77796
K= 85	Y2(K) = 5.96255	X2(K) = -0.78003
K= 86	Y2(K) = 5.95371	X2(K) = -0.78203
K= 87	Y2(K) = 5.94496	X2(K) = -0.78397
K= 88	Y2(K) = 5.93630	X2(K) = -0.78586
K= 89	Y2(K) = 5.92775	X2(K) = -0.78768
K= 90	Y2(K) = 5.91929	X2(K) = -0.78944
K= 91	Y2(K) = 5.91093	X2(K) = -0.79114
K= 92	Y2(K) = 5.90267	X2(K) = -0.79279
K= 93	Y2(K) = 5.89450	X2(K) = -0.79438
K= 94	Y2(K) = 5.88644	X2(K) = -0.79591
K= 95	Y2(K) = 5.87847	X2(K) = -0.79739
K= 96	Y2(K) = 5.87060	X2(K) = -0.79882
K= 97	Y2(K) = 5.86283	X2(K) = -0.80019
K= 98	Y2(K) = 5.85516	X2(K) = -0.80151
K= 99	Y2(K) = 5.84760	X2(K) = -0.80278
K= 100	Y2(K) = 5.84013	X2(K) = -0.80400
K= 101	Y2(K) = 5.83278	X2(K) = -0.80517
K= 102	Y2(K) = 5.82550	X2(K) = -0.80629
K= 103	Y2(K) = 5.81833	X2(K) = -0.80736
K= 104	Y2(K) = 5.81127	X2(K) = -0.80839
K= 105	Y2(K) = 5.80431	X2(K) = -0.80937
K= 106	Y2(K) = 5.79745	X2(K) = -0.81030
K= 107	Y2(K) = 5.79069	X2(K) = -0.81120
K= 108	Y2(K) = 5.78404	X2(K) = -0.81205
K= 109	Y2(K) = 5.77749	X2(K) = -0.81285
K= 110	Y2(K) = 5.77104	X2(K) = -0.81362
K= 111	Y2(K) = 5.76469	X2(K) = -0.81434
K= 112	Y2(K) = 5.75845	X2(K) = -0.81503
K= 113	Y2(K) = 5.75232	X2(K) = -0.81567
K= 114	Y2(K) = 5.74628	X2(K) = -0.81628
K= 115	Y2(K) = 5.74035	X2(K) = -0.81686
K= 116	Y2(K) = 5.73453	X2(K) = -0.81739

K= 117	Y2(K) =	5.72881	X2(K) = -0.81790
K= 118	Y2(K) =	5.72319	X2(K) = -0.81836
K= 119	Y2(K) =	5.71768	X2(K) = -0.81880
K= 120	Y2(K) =	5.71228	X2(K) = -0.81920
K= 121	Y2(K) =	5.70698	X2(K) = -0.81958
K= 122	Y2(K) =	5.70179	X2(K) = -0.81992
K= 123	Y2(K) =	5.69670	X2(K) = -0.82023
K= 124	Y2(K) =	5.69172	X2(K) = -0.82052
K= 125	Y2(K) =	5.68684	X2(K) = -0.82077
K= 126	Y2(K) =	5.68207	X2(K) = -0.82100
K= 127	Y2(K) =	5.67741	X2(K) = -0.82121
K= 128	Y2(K) =	5.67285	X2(K) = -0.82139
K= 129	Y2(K) =	5.66840	X2(K) = -0.82155
K= 130	Y2(K) =	5.66405	X2(K) = -0.82168
K= 131	Y2(K) =	5.65982	X2(K) = -0.82179
K= 132	Y2(K) =	5.65569	X2(K) = -0.82188
K= 133	Y2(K) =	5.65166	X2(K) = -0.82196
K= 134	Y2(K) =	5.64775	X2(K) = -0.82201
K= 135	Y2(K) =	5.64394	X2(K) = -0.82204
K= 136	Y2(K) =	5.64023	X2(K) = -0.82206
K= 137	Y2(K) =	5.63664	X2(K) = -0.82206
K= 138	Y2(K) =	5.63315	X2(K) = -0.82205
K= 139	Y2(K) =	5.62977	X2(K) = -0.82202
K= 140	Y2(K) =	5.62650	X2(K) = -0.82198
K= 141	Y2(K) =	5.62335	X2(K) = -0.82192
K= 142	Y2(K) =	5.62028	X2(K) = -0.82186
K= 143	Y2(K) =	5.61733	X2(K) = -0.82178
K= 144	Y2(K) =	5.61448	X2(K) = -0.82170
K= 145	Y2(K) =	5.61175	X2(K) = -0.82160
K= 146	Y2(K) =	5.60912	X2(K) = -0.82150
K= 147	Y2(K) =	5.60660	X2(K) = -0.82139
K= 148	Y2(K) =	5.60419	X2(K) = -0.82127
K= 149	Y2(K) =	5.60189	X2(K) = -0.82115
K= 150	Y2(K) =	5.59969	X2(K) = -0.82103
K= 151	Y2(K) =	5.59760	X2(K) = -0.82090
K= 152	Y2(K) =	5.59562	X2(K) = -0.82077

TROCHOID

K= 153	Y2(K) =	5.58996	X2(K) = -0.81907
K= 154	Y2(K) =	5.56340	X2(K) = -0.81158
K= 155	Y2(K) =	5.53706	X2(K) = -0.80462
K= 156	Y2(K) =	5.51095	X2(K) = -0.79817
K= 157	Y2(K) =	5.48501	X2(K) = -0.79223
K= 158	Y2(K) =	5.45931	X2(K) = -0.78680
K= 159	Y2(K) =	5.43383	X2(K) = -0.78188
K= 160	Y2(K) =	5.40857	X2(K) = -0.77746
K= 161	Y2(K) =	5.38353	X2(K) = -0.77355
K= 162	Y2(K) =	5.35871	X2(K) = -0.77015
K= 163	Y2(K) =	5.33411	X2(K) = -0.76725
K= 164	Y2(K) =	5.30972	X2(K) = -0.76485
K= 165	Y2(K) =	5.28555	X2(K) = -0.76296
K= 166	Y2(K) =	5.26159	X2(K) = -0.76158
K= 167	Y2(K) =	5.23784	X2(K) = -0.76071
K= 168	Y2(K) =	5.21430	X2(K) = -0.76036
K= 169	Y2(K) =	5.19098	X2(K) = -0.76052
K= 170	Y2(K) =	5.16783	X2(K) = -0.76122
K= 171	Y2(K) =	5.14489	X2(K) = -0.76245
K= 172	Y2(K) =	5.12214	X2(K) = -0.76422

K=	173	Y2(K) =	5.09958	X2(K) =	-0.76655
K=	174	Y2(K) =	5.07720	X2(K) =	-0.76945
K=	175	Y2(K) =	5.05500	X2(K) =	-0.77293
K=	176	Y2(K) =	5.03298	X2(K) =	-0.77702
K=	177	Y2(K) =	5.01112	X2(K) =	-0.78172
K=	178	Y2(K) =	4.98943	X2(K) =	-0.78708
K=	179	Y2(K) =	4.96791	X2(K) =	-0.79312
K=	180	Y2(K) =	4.94656	X2(K) =	-0.79985
K=	181	Y2(K) =	4.92537	X2(K) =	-0.80733
K=	182	Y2(K) =	4.90436	X2(K) =	-0.81559
K=	183	Y2(K) =	4.88359	X2(K) =	-0.82466
K=	184	Y2(K) =	4.86293	X2(K) =	-0.83460
K=	185	Y2(K) =	4.84255	X2(K) =	-0.84545
K=	186	Y2(K) =	4.82242	X2(K) =	-0.85726
K=	187	Y2(K) =	4.80260	X2(K) =	-0.87008
K=	188	Y2(K) =	4.78312	X2(K) =	-0.88396
K=	189	Y2(K) =	4.76407	X2(K) =	-0.89895
K=	190	Y2(K) =	4.74550	X2(K) =	-0.91509
K=	191	Y2(K) =	4.72752	X2(K) =	-0.93241
K=	192	Y2(K) =	4.71022	X2(K) =	-0.95094
K=	193	Y2(K) =	4.69372	X2(K) =	-0.97068
K=	194	Y2(K) =	4.67816	X2(K) =	-0.99162
K=	195	Y2(K) =	4.66365	X2(K) =	-1.01372
K=	196	Y2(K) =	4.65034	X2(K) =	-1.03692
K=	197	Y2(K) =	4.63836	X2(K) =	-1.06113
K=	198	Y2(K) =	4.62784	X2(K) =	-1.08623
K=	199	Y2(K) =	4.61887	X2(K) =	-1.11207
K=	200	Y2(K) =	4.61155	X2(K) =	-1.13850
K=	201	Y2(K) =	4.60593	X2(K) =	-1.16535
K=	202	Y2(K) =	4.60203	X2(K) =	-1.19241
K=	203	Y2(K) =	4.59987	X2(K) =	-1.21952
K=	204	Y2(K) =	4.59940	X2(K) =	-1.24650
K=	205	Y2(K) =	4.60056	X2(K) =	-1.27319

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N = 12.00000     BEFF =  1.05260     PD =  1.00000

THETAC = 20.00000     QAPTCG =  1.57079     RC =  0.30000

KACC =  1.00000


DELAL =  0.25000     DELPSI =  0.05000     DELCON=   0.00100     CONB =  4.00000

*****   TOOTH IS UNDERCUT   *****

RP =  6.00000     RB =  5.63816     RO =  7.00000     RF =  5.65550

THETAB = 16.70787     GAPT = 26.16565     EPS = 28.35393     DELTA =  0.0     TAU = 28.35393

ALPHIN =  4.49751     ALPHFIN = 42.15911

PSIIN =  8.97017     PSIFIN =-17.19948

PHIRC = 36.34621     BETA = 33.80518     CAPTO =  0.62089     THETAO =  2.54104

RV =  6.78532


EX =  0.34447     YLEWIS =  0.22965     YAGMA =  0.23635

TANGENCY K =385     Y2(KTAN) =  5.02859     X2(KTAN) =-0.777906     XPAR TAN = 0.777909     CONB = 2.903

        WRITE =1
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INVOLUTE PLOT

K=	1	Y2(K) =	6.99844	X2(K) =	-0.30677
K=	2	Y2(K) =	6.98340	X2(K) =	-0.31683
K=	3	Y2(K) =	6.96841	X2(K) =	-0.32676
K=	4	Y2(K) =	6.95347	X2(K) =	-0.33656
K=	5	Y2(K) =	6.93858	X2(K) =	-0.34624
K=	6	Y2(K) =	6.92373	X2(K) =	-0.35580
K=	7	Y2(K) =	6.90893	X2(K) =	-0.36523
K=	8	Y2(K) =	6.89418	X2(K) =	-0.37454
K=	9	Y2(K) =	6.87949	X2(K) =	-0.38373
K=	10	Y2(K) =	6.86484	X2(K) =	-0.39280
K=	11	Y2(K) =	6.85025	X2(K) =	-0.40175
K=	12	Y2(K) =	6.83570	X2(K) =	-0.41058
K=	13	Y2(K) =	6.82122	X2(K) =	-0.41930
K=	14	Y2(K) =	6.80678	X2(K) =	-0.42789
K=	15	Y2(K) =	6.79240	X2(K) =	-0.43636
K=	16	Y2(K) =	6.77808	X2(K) =	-0.44472
K=	17	Y2(K) =	6.76382	X2(K) =	-0.45297
K=	18	Y2(K) =	6.74961	X2(K) =	-0.46109
K=	19	Y2(K) =	6.73546	X2(K) =	-0.46911
K=	20	Y2(K) =	6.72137	X2(K) =	-0.47700
K=	21	Y2(K) =	6.70733	X2(K) =	-0.48479
K=	22	Y2(K) =	6.69336	X2(K) =	-0.49246
K=	23	Y2(K) =	6.67945	X2(K) =	-0.50002
K=	24	Y2(K) =	6.66560	X2(K) =	-0.50746
K=	25	Y2(K) =	6.65181	X2(K) =	-0.51480
K=	26	Y2(K) =	6.63809	X2(K) =	-0.52203
K=	27	Y2(K) =	6.62443	X2(K) =	-0.52914
K=	28	Y2(K) =	6.61084	X2(K) =	-0.53615
K=	29	Y2(K) =	6.59731	X2(K) =	-0.54305
K=	30	Y2(K) =	6.58384	X2(K) =	-0.54984
K=	31	Y2(K) =	6.57044	X2(K) =	-0.55653
K=	32	Y2(K) =	6.55711	X2(K) =	-0.56311
K=	33	Y2(K) =	6.54385	X2(K) =	-0.56958
K=	34	Y2(K) =	6.53066	X2(K) =	-0.57595
K=	35	Y2(K) =	6.51753	X2(K) =	-0.58222
K=	36	Y2(K) =	6.50448	X2(K) =	-0.58838
K=	37	Y2(K) =	6.49149	X2(K) =	-0.59444
K=	38	Y2(K) =	6.47858	X2(K) =	-0.60040
K=	39	Y2(K) =	6.46574	X2(K) =	-0.60625
K=	40	Y2(K) =	6.45297	X2(K) =	-0.61201
K=	41	Y2(K) =	6.44027	X2(K) =	-0.61767
K=	42	Y2(K) =	6.42765	X2(K) =	-0.62323
K=	43	Y2(K) =	6.41510	X2(K) =	-0.62869
K=	44	Y2(K) =	6.40263	X2(K) =	-0.63405
K=	45	Y2(K) =	6.39023	X2(K) =	-0.63932
K=	46	Y2(K) =	6.37791	X2(K) =	-0.64449
K=	47	Y2(K) =	6.36566	X2(K) =	-0.64957
K=	48	Y2(K) =	6.35349	X2(K) =	-0.65455
K=	49	Y2(K) =	6.34140	X2(K) =	-0.65944
K=	50	Y2(K) =	6.32939	X2(K) =	-0.66424
K=	51	Y2(K) =	6.31746	X2(K) =	-0.66894
K=	52	Y2(K) =	6.30561	X2(K) =	-0.67356
K=	53	Y2(K) =	6.29384	X2(K) =	-0.67808
K=	54	Y2(K) =	6.28214	X2(K) =	-0.68251
K=	55	Y2(K) =	6.27053	X2(K) =	-0.68686

K=	56	Y2(K) =	6.25900	X2(K) =	-0.69112
K=	57	Y2(K) =	6.24756	X2(K) =	-0.69529
K=	58	Y2(K) =	6.23620	X2(K) =	-0.69937
K=	59	Y2(K) =	6.22492	X2(K) =	-0.70337
K=	60	Y2(K) =	6.21372	X2(K) =	-0.70728
K=	61	Y2(K) =	6.20261	X2(K) =	-0.71111
K=	62	Y2(K) =	6.19158	X2(K) =	-0.71486
K=	63	Y2(K) =	6.18064	X2(K) =	-0.71852
K=	64	Y2(K) =	6.16979	X2(K) =	-0.72211
K=	65	Y2(K) =	6.15902	X2(K) =	-0.72561
K=	66	Y2(K) =	6.14834	X2(K) =	-0.72903
K=	67	Y2(K) =	6.13774	X2(K) =	-0.73238
K=	68	Y2(K) =	6.12724	X2(K) =	-0.73564
K=	69	Y2(K) =	6.11682	X2(K) =	-0.73883
K=	70	Y2(K) =	6.10649	X2(K) =	-0.74194
K=	71	Y2(K) =	6.09625	X2(K) =	-0.74498
K=	72	Y2(K) =	6.08611	X2(K) =	-0.74794
K=	73	Y2(K) =	6.07605	X2(K) =	-0.75083
K=	74	Y2(K) =	6.06608	X2(K) =	-0.75364
K=	75	Y2(K) =	6.05620	X2(K) =	-0.75639
K=	76	Y2(K) =	6.04642	X2(K) =	-0.75906
K=	77	Y2(K) =	6.03673	X2(K) =	-0.76166
K=	78	Y2(K) =	6.02713	X2(K) =	-0.76419
K=	79	Y2(K) =	6.01762	X2(K) =	-0.76665
K=	80	Y2(K) =	6.00820	X2(K) =	-0.76905
K=	81	Y2(K) =	5.99888	X2(K) =	-0.77137
K=	82	Y2(K) =	5.98966	X2(K) =	-0.77363
K=	83	Y2(K) =	5.98053	X2(K) =	-0.77583
K=	84	Y2(K) =	5.97149	X2(K) =	-0.77796
K=	85	Y2(K) =	5.96255	X2(K) =	-0.78003
K=	86	Y2(K) =	5.95371	X2(K) =	-0.78203
K=	87	Y2(K) =	5.94498	X2(K) =	-0.78397
K=	88	Y2(K) =	5.93630	X2(K) =	-0.78586
K=	89	Y2(K) =	5.92775	X2(K) =	-0.78768
K=	90	Y2(K) =	5.91929	X2(K) =	-0.78944
K=	91	Y2(K) =	5.91095	X2(K) =	-0.79114
K=	92	Y2(K) =	5.90267	X2(K) =	-0.79279
K=	93	Y2(K) =	5.89450	X2(K) =	-0.79438
K=	94	Y2(K) =	5.88644	X2(K) =	-0.79591
K=	95	Y2(K) =	5.87847	X2(K) =	-0.79739
K=	96	Y2(K) =	5.87060	X2(K) =	-0.79882
K=	97	Y2(K) =	5.86283	X2(K) =	-0.80019
K=	98	Y2(K) =	5.85516	X2(K) =	-0.80151
K=	99	Y2(K) =	5.84760	X2(K) =	-0.80278
K=	100	Y2(K) =	5.84013	X2(K) =	-0.80400
K=	101	Y2(K) =	5.83276	X2(K) =	-0.80517
K=	102	Y2(K) =	5.82550	X2(K) =	-0.80629
K=	103	Y2(K) =	5.81835	X2(K) =	-0.80736
K=	104	Y2(K) =	5.81127	X2(K) =	-0.80839
K=	105	Y2(K) =	5.80431	X2(K) =	-0.80937
K=	106	Y2(K) =	5.79745	X2(K) =	-0.81030
K=	107	Y2(K) =	5.79069	X2(K) =	-0.81120
K=	108	Y2(K) =	5.78404	X2(K) =	-0.81205
K=	109	Y2(K) =	5.77749	X2(K) =	-0.81285
K=	110	Y2(K) =	5.77104	X2(K) =	-0.81362
K=	111	Y2(K) =	5.76469	X2(K) =	-0.81434
K=	112	Y2(K) =	5.75845	X2(K) =	-0.81503
K=	113	Y2(K) =	5.75232	X2(K) =	-0.81567
K=	114	Y2(K) =	5.74628	X2(K) =	-0.81628
K=	115	Y2(K) =	5.74035	X2(K) =	-0.81686
K=	116	Y2(K) =	5.73453	X2(K) =	-0.81739

K=	117	Y2(K) =	5.72881	X2(K) =	-0.81790
K=	118	Y2(K) =	5.72319	X2(K) =	-0.81836
K=	119	Y2(K) =	5.71768	X2(K) =	-0.81880
K=	120	Y2(K) =	5.71228	X2(K) =	-0.81920
K=	121	Y2(K) =	5.70698	X2(K) =	-0.81958
K=	122	Y2(K) =	5.70179	X2(K) =	-0.81992
K=	123	Y2(K) =	5.69670	X2(K) =	-0.82023
K=	124	Y2(K) =	5.69172	X2(K) =	-0.82052
K=	125	Y2(K) =	5.68684	X2(K) =	-0.82077
K=	126	Y2(K) =	5.68207	X2(K) =	-0.82100
K=	127	Y2(K) =	5.67741	X2(K) =	-0.82121
K=	128	Y2(K) =	5.67285	X2(K) =	-0.82139
K=	129	Y2(K) =	5.66840	X2(K) =	-0.82155
K=	130	Y2(K) =	5.66405	X2(K) =	-0.82168
K=	131	Y2(K) =	5.65982	X2(K) =	-0.82179
K=	132	Y2(K) =	5.65569	X2(K) =	-0.82188
K=	133	Y2(K) =	5.65166	X2(K) =	-0.82196
K=	134	Y2(K) =	5.64775	X2(K) =	-0.82201
K=	135	Y2(K) =	5.64394	X2(K) =	-0.82204
K=	136	Y2(K) =	5.64023	X2(K) =	-0.82206
K=	137	Y2(K) =	5.63664	X2(K) =	-0.82206
K=	138	Y2(K) =	5.63315	X2(K) =	-0.82205
K=	139	Y2(K) =	5.62977	X2(K) =	-0.82202
K=	140	Y2(K) =	5.62650	X2(K) =	-0.82198
K=	141	Y2(K) =	5.62333	X2(K) =	-0.82192
K=	142	Y2(K) =	5.62028	X2(K) =	-0.82186
K=	143	Y2(K) =	5.61733	X2(K) =	-0.82178
K=	144	Y2(K) =	5.61448	X2(K) =	-0.82170
K=	145	Y2(K) =	5.61175	X2(K) =	-0.82160
K=	146	Y2(K) =	5.60912	X2(K) =	-0.82150
K=	147	Y2(K) =	5.60660	X2(K) =	-0.82139
K=	148	Y2(K) =	5.60419	X2(K) =	-0.82127
K=	149	Y2(K) =	5.60189	X2(K) =	-0.82115
K=	150	Y2(K) =	5.59969	X2(K) =	-0.82103
K=	151	Y2(K) =	5.59760	X2(K) =	-0.82090
K=	152	Y2(K) =	5.59562	X2(K) =	-0.82077

TROCHOID PLOT

K=	153	Y2(K) =	5.58996	X2(K) =	-0.81907
K=	154	Y2(K) =	5.58729	X2(K) =	-0.81830
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K=	157	Y2(K) =	5.57931	X2(K) =	-0.81601
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K=	159	Y2(K) =	5.57400	X2(K) =	-0.81452
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K=	161	Y2(K) =	5.56870	X2(K) =	-0.81304
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K=	163	Y2(K) =	5.56340	X2(K) =	-0.81158
K=	164	Y2(K) =	5.56076	X2(K) =	-0.81086
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K=	166	Y2(K) =	5.55548	X2(K) =	-0.80944
K=	167	Y2(K) =	5.55284	X2(K) =	-0.80874
K=	168	Y2(K) =	5.55020	X2(K) =	-0.80804
K=	169	Y2(K) =	5.54757	X2(K) =	-0.80734
K=	170	Y2(K) =	5.54494	X2(K) =	-0.80665
K=	171	Y2(K) =	5.54231	X2(K) =	-0.90597
K=	172	Y2(K) =	5.53968	X2(K) =	-0.80529

K=	173	Y2(K) =	5.53706	X2(K) =	-0.80462
K=	174	Y2(K) =	5.53443	X2(K) =	-0.80395
K=	175	Y2(K) =	5.53181	X2(K) =	-0.80329
K=	176	Y2(K) =	5.52920	X2(K) =	-0.80263
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K=	183	Y2(K) =	5.51093	X2(K) =	-0.79817
K=	184	Y2(K) =	5.50832	X2(K) =	-0.79755
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K=	186	Y2(K) =	5.50313	X2(K) =	-0.79633
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K=	212	Y2(K) =	5.43637	X2(K) =	-0.78235
K=	213	Y2(K) =	5.43383	X2(K) =	-0.78188
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